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ADVANCED UNMANNED SEARCH SYSTEM (AUSS) PERFORMANCE ANALYSIS

SB Bryant

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Prepared for
Naval Sea Systems Command

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

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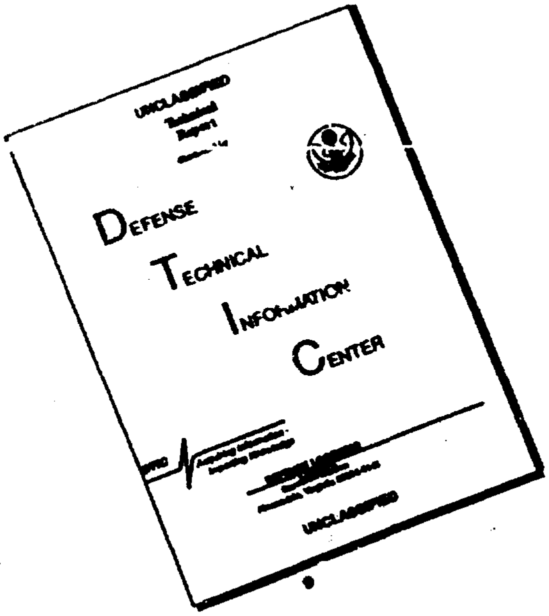

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ADMINISTRATIVE INFORMATION

The analysis reported herein was performed from October 1978 to June 1979 by J. L. Held and S. B. Bryant. The mean performance time algorithms of Appendix C were provided by Dr. Alan Gordon. The work was sponsored by the Deep Ocean Technology Project, NAVSEA Code 05R2, Project Element 63713N, Project Number S0397, Task Number 12623. The report has been received for technical accuracy by Dr. Alan Gordon.

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Determine if an advanced unmanned search system can be devised, using new combinations of state-of-the-art components and techniques, that will significantly extend the Navy's present search capability. Conduct the analysis with the AUSS Deep Ocean Search Performance Model, a large-scale simulation program.

Following extensive preliminary analyses, seven unmanned search systems were proposed and subjected to a complete performance and risk analysis. For the 20,000-foot search case, the new systems offered between 4.6 and 37.6 times the search rate of the Navy's current capability. The best system was an acoustically linked vehicle that used a scanning sonar for broad-area search and slow-scan video as a viewfinder for final evaluation and inspection.

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SUMMARY

PROBLEM

Determine if an advanced unmanned search system can be devised, using new combinations of state-of-the-art components and techniques, that will significantly extend the Navy's present search capability. Conduct the analysis with the AUSS Deep Ocean Search Performance Model, a large-scale simulation program.

RESULTS

Following extensive preliminary analyses, seven unmanned search systems were proposed and subjected to a complete performance and risk analysis. For the 20,000-foot search case, the new systems offered between 4.6 and 37.6 times the search rate of the Navy's current capability. The best system was an acoustically linked vehicle that used a scanning sonar for broad-area search and slow-scan video as a viewfinder for final evaluation and inspection.

RECOMMENDATIONS

Improved search rates were predicted for both tethered and untethered search systems. The search community should be made aware of the suggested configurations and possible benefits. Test programs should be generated to confirm the feasibility of the acoustically linked vehicle with scanning sonar for broad-area search.

CONTENTS

INTRODUCTION

The goal of the FY 79 Advanced Unmanned Search System (AUSS) Performance Analysis was to determine if unmanned search systems could be devised, using new combinations of state-of-the-art components and techniques, that would significantly extend present search capabilities. The analysis was performed with the aid of the AUSS Deep Ocean Floor Search Performance Model, a large-scale simulation program developed at NOSC from 1973 through 1978. The model is described in Appendix A.

The system selected as a baseline search system was the Surface Towed Search System currently under development for Submarine Development Group One. This baseline towed system, as used in AUSS model searches, will first conduct a broad-area search using a side-look sonar (SLS) (with a forward-look sonar for coverage of the SLS gap) and then conduct a contact evaluation phase using a television camera as viewfinder for a photographic camera. The figure of merit with which new system concepts are to be compared with the baseline towed system is the on-site search rate (the area of a cell serviceable by a single bottom-mounted transponder grid divided by the on-scene time required to search that area, usually expressed in square nautical miles per hour). The search rate for a given system is highly dependent on the given search problem – the environmental conditions, target size, tactics used, and so on – and reasonable care must be exercised to keep the problem consistent in making system-to-system comparisons. In all, seven new concepts were evaluated that offer, for the 20,000-foot deep search case, between 4.6 and 37.6 times the baseline search rate depending on the system used and the given search problem. The analysis leading up to these results was performed in five sequential phases:

(1) *Sensitivity Analysis.* The first step of the FY 79 AUSS program was to assess the effect of specific system capabilities on overall search rates. For example: How sensitive is the search rate to the sonar swath width? To the video swath width? To search speed? Results were obtained for approximately fifteen system variables, for two search systems (the baseline towed system and a corresponding free-swimmer that carried the same sensors and used similar search tactics), and for three search scenarios. These results provided considerable insight as to which system capabilities were worth attention in the design of new, more effecient search systems.

(2) *Optimization Study*. The optimization study was a more detailed version of the sensitivity analysis. In this instance, a state-of-the-art limit was assessed for each of the system variables and search rates were obtained for the same two search systems (baseline towed and corresponding free-swimmer) by sequentially pushing each variable to its state-of-the-art limit.* Graphs were produced that revealed the percentage increase each optimized variable contributed to the overall search rate. These results, along with the more general sensitivity analysis, provided the necessary background and direction for the hypothesis of new, more efficient search system configurations.

(3) *Development of Candidate Systems*. Approximately thirty new systems concepts were considered in a series of engineering evaluation sessions, of which seven were selected as promising enough to warrant an extensive performance analysis. The seven systems take advantage of the sensitivity analysis and optimization study results, maximizing the performance of the most promising subsystem variables.

*The term "state-of-the-art" implies in this case that the hardware or technique has either been built or demonstrated. All components or techniques analyzed in this study were drawn from openly advertised or published sources.

(4) *Risk Analysis.* Although each of the candidate systems incorporates only proven, state-of-the-art technology, that technology for some systems was still relatively new or was used in a new configuration, meaning that some degree of risk would be involved. For all systems, this critical technology was identified and summarized, along with system characteristics and system advantages, in tabular form.

(5) *Performance Analysis.* A comprehensive performance analysis was conducted on the baseline towed system and on the seven candidate towed systems, resulting in a rigorous and fair system-by-system comparison. Results were obtained for two scenarios (shallow and deep) and for four target lengths (from 10 to 300 feet). All candidate systems, for all situations, exhibited a significantly improved search rate relative to the baseline towed system rate.

Each of these five phases of the analysis is discussed in detail in the following five sections of this report.

SENSITIVITY ANALYSIS

INTRODUCTION

The initial step of the FY 79 AUSS Performance Analysis was a sensitivity analysis of the baseline towed system and a corresponding free-swimmer. Through this analysis, the effect of specific system capabilities on each system's overall search rate was determined. Specifically, the goal of this analysis was not to compare the capabilities of a towed system with those of a free-swimmer, but was to determine how a single variable, such as sensor swath width, affected the performance of a "typical" towed system or a "typical" free-swimmer.

Only one capability at a time was varied. For example, while generating a curve of search rate as a function of sonar swath width, all other variables were held constant. The sonar swath was then reset to its baseline value before proceeding to the next variable, such as video swath width.

To accomplish the sensitivity analysis, it was necessary to agree upon a standard or baseline set of capabilities for each system type. Along with this, there had to be a standard set of search tactics and one or more standard scenarios (a "scenario" is the set of conditions describing the search environment and the target size and condition). Note that there was nothing inherently sacrosanct in the choices of the baseline system types or scenarios: each was merely an agreed-upon set of capabilities and conditions (hoped to be realistic and somewhat conservative), a sort of software test bed with which the importance of specific system capabilities could be gauged. With this provision set forth, this section of this report documents these "realistic and somewhat conservative" choices for the towed and free-swimmer systems.

BASELINE CRITERIA

Baseline Scenarios

In selecting baseline scenarios, the goal was to encompass the full range of anticipated target sizes, depths, terrains, and water clarities in a minimum number of realistic cases. The smallest target selected was an H-bomb, the largest an attack submarine. Both were considered to be intact. The H-bomb search was performed at 2000 feet, the submarine search at 8400 feet. An additional submarine search was selected at 20,000 feet to complete the range of anticipated depths. The H-bomb search was performed in the worst terrain (scarp), the submarine search in the best (smooth bottom). The H-bomb search was conducted in the worst water clarity (coastal), the submarine search in the best (deep ocean). Search cell sizes were limited to those serviceable by a single long baseline transponder grid (about 4 nautical miles per side). The H-bomb search was constrained to an actual search area of 2 X 10 nautical miles. Search rates were calculated for a single search cell only. AUSS model inputs to the three baseline scenarios are summarized in Table 1. Note that the deep and middle-depth cases are identical scenarios except for depth.

Baseline Systems: Philosophy

The guideline for selecting baseline systems was that they be realistic, that they not challenge state-of-the-art credibility. The choice for the towed system was the

Table 1. Baseline scenarios.

SHALLOW CASE (H-BOMB SEARCH AT 2000 FEET)

- Rectangular area
- 5 nmi X 2 nmi
- 2000-foot depth
- Scarp terrain
- Coastal waters
- Sea state 3
- Intact target
- Cylindrical target
- 1-foot radius X 10-foot radius

MIDDLE DEPTH CASE (SUBMARINE SEARCH AT 8400 FEET)

- Square area
- 4 nmi X 4 nmi
- 8400-foot depth
- Smooth terrain
- Open ocean waters
- Sea state 3
- Intact target
- Cylindrical target
- 12.5-foot radius X 300-foot length

DEEP CASE (SUBMARINE SEARCH AT 20,000 FEET)

- Square area
- 4 nmi X 4 nmi
- 20,000-foot depth
- Smooth terrain
- Open ocean waters
- Sea state 3
- Intact target
- Cylindrical target
- 12.5-foot radius X 300-foot radius

SUMMARY: Except for the differences in depth, the shallow case constitutes a search for a very small object in the worst terrain conditions and the worst water clarity; the middle and deep cases constitute searches for very large objects in the best terrain conditions and the best water clarities.

Surface Towed Search System being developed for Submarine Development Group One, San Diego, with the capabilities and search tactics of the system defined by original performance specifications and implemented within the limitations of the AUSS model. It should again be emphasized that any baseline system used in the sensitivity analysis was an arbitrary choice, used only for assessing the impacts of specific capabilities. The interest was in percentage improvements resulting from enhanced system capabilities, not in absolute *(arbitrary)* performance rates. Later in the program, various proposed systems were competitively compared with the baseline towed system against a variety of scenarios. A free-swimmer was also agreed upon that conformed as closely as possible to the baseline towed system (same sensors, same search tactics, etc.). Specific capabilities of these systems are defined below.

Baseline Towed System

AUSS model inputs that describe the baseline towed system are presented in Table 2.

Baseline Free Swimmer

For the baseline free-swimmer, the same sensor inputs and general tactics used in the towed case were duplicated. Differences from the towed case are as follows:

(a) Energy endurance: 5 hours. Vehicle weight is calculated as a function of speed, power consumption, and desired energy endurance. A choice of 5 hours produces reasonable results. At 5 hours, it was assumed that energy endurance, not data storage, would be the limiting bottom time factor.

(b) Speed: 5 knots. The baseline towed system should work well at speeds up to 5 knots. This speed therefore was considered reasonable for both search and evaluation.

(c) Ascent/descent rates: Ascent/descent was conservatively modeled by allowing the vehicle to climb and descend under its own power (thereby consuming energy) at a 90-degree angle (vertical ascent/descent).

(d) Turn times: Calculated (as opposed to given) assuming a 5-knot speed.

(e) Control error: 0 feet. With the cable-ship interfaces eliminated, the only localization problem should be navigation error.

(f) Miscellaneous: There were minor changes in the AUSS canned free-swimmer design. Titanium was chosen over aluminum to better meet the 20,000-foot requirement, and the pressure cylinder internal diameter was set at 12 inches.

System Inputs

Baseline system parameters and scenario data are entered into the AUSS computer model via a series of questions and answers on a computer terminal. A sample series of those questions and answers appears in Appendix A.

System Variables

Search rates were obtained for both search systems, for all three scenarios, for the following system variables:

search swath
evaluation swath
search sensor swath detection probability

Table 2. Baseline towed system values for sensitivity analysis as required for inputs to AUSS model.

Item	Value	Comments
Navigation	Long baseline	RMS navigation error is approximately 60 feet with this system.
Vehicle type	Towed	
Sensor suit (search)	Side-look sonar (SLS) with forward-look sonar (FLS) for gap fill in	
• Velocity	1.5 knots	
• Op height	200 feet (deep, middle), 33.7 feet (shallow)	
• Swath	2000 feet (deep, middle) 330 feet shallow	2000 feet was a quoted capability, and was used in Sensitivity Analysis. In later analyses (Optimization Study and Candidate System Performance Analysis), specific sonar parameters (beam width, frequency, etc.) were used, and AUSS model calculated the swath.
• Gap width	0 feet	Assumes FLS fills SLS gap.
• Total swath detection probability	0.9	
• Payload volume	1.8 $feet^3$	
• Payload weight	200 pounds (air)	
• Max. depth limit	None	
• Power required	1.1 kilowatts	
• Required bandwidth	700 kilohertz	
• Sensor resolution	3 feet (at max. swath)	
• Degraded channel capacity factor	3.0	
• S/N ratio	30 dB	
• False target density	0.13 per square nautical mile for deep and mid-range (submarine target) 2.7 per square nautical mile for shallow (bomb target)	These values are averages of several situations catalogued in the AUSS model.*
• Users error probability	1E-3	
Sensor suit (evaluation)	Video camera, used as view-finder for photographic camera	
• Transmit to surface	Yes (TV)	Although primary baseline towed system evaluation sensor is

*From "The Size Distribution of Side-Looking Sonar Targets," by Stephen Miller, Marine Physical Laboratory, Scripps Institution of Oceanography, January 1977.

Table 2. Baseline towed system values for sensitivity analysis as required for inputs to AUSS model (Continued).

Item	Value	Comments
		photographic, a video camera viewfinder is used. This sensor is therefore the limiting factor in the context of the AUSS model.
• OPS velocity	1.5 knots	
• OPS height	30 feet	
• OPS swath	21.8 feet	
• Gap width	0 feet	
• Swath detection probability	0.999	
• Maximum bottom time	Unlimited	
• Processing time	None	
• Payload weight	30 pounds	
• Payload volume	0.2 feet^3	
• Maximum depth limit	None	
• Total power required	1.8 kilowatts	
• Required bandwith	600 kilohertz	
• Resolution	0.5 feet	
• Degraded channel capacity factor	3	
• Number of bits required	5	
• User's error probability	1E-3	
Cable design (users)		
• Segments	50	
• Normal drag coefficient	1.7	
• Tangential drag coefficient	0.01	
• Diameter	0.7 inches	
• Weight in water	0.5 pounds/foot	
• Segment printout frequency	5	

Table 2. Baseline towed system values for sensitivity analysis as required for inputs to AUSS model (Continued).

Item	Value	Comments
Vehicle		
• Best/design heights and speeds		
• Control error (search)	600 feet (deep, middle), 100 feet (shallow).	
• Control error (evaluation)	600 feet (deep, middle), 100 feet (shallow).	
Tactics		
• Search pattern	Parallel path	
• Search coverage	Minimum track	
• Evaluation pattern	Rectangular Spiral	
• Evaluation transit speed	Same as evaluation speed	
• Track overlap (search)	0.5	
• Total probability (search)	0.9	
Changes		
• Search turn time/turn	2 hours (deep) 2 hours (middle) 1 hour (shallow)	
• Evaluation turn time/turn	0 hours	
• Ascent rate	12,000 feet/hour	
• Descent rate	12,000 feet/hour	
• Frame type	Streamlined	
• Material	Fiberglass	
• Length	10.5 feet	
• Weight (in water)	941.2 pounds	
• Axial drag coefficient	0.38	

evaluation sensor swath detection probability
search velocity
evaluation velocity
rms navigation error
search control error
evaluation control error
search area detection probability (desired)
evaluation area detection probability (desired)
search time per turn
evaluation time per turn
ascent rate
descent rate
launch time
recovery time
deck time
search track overlap
evaluation track overlap
search pattern
evaluation pattern
false target density

RESULTS

Typical search rate versus system variable curves are presented in Figures 1 through 3. The complete set of Sensitivity Analysis curves are presented in Appendix B. There is no single conclusion that one can draw from the Sensitivity Analysis. The curves in Appendix B constitute a complete catalog of results available to the system designer for drawing conclusions on specific questions. In the next phase of the analysis, the Optimization Study, more general conclusions become apparent.

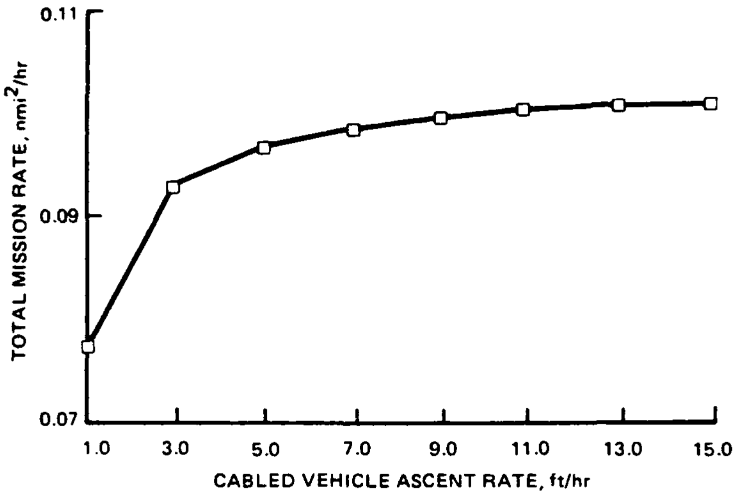

Figure 1. Baseline towed system deep scenario: total mission rate versus cabled vehicle ascent rate.

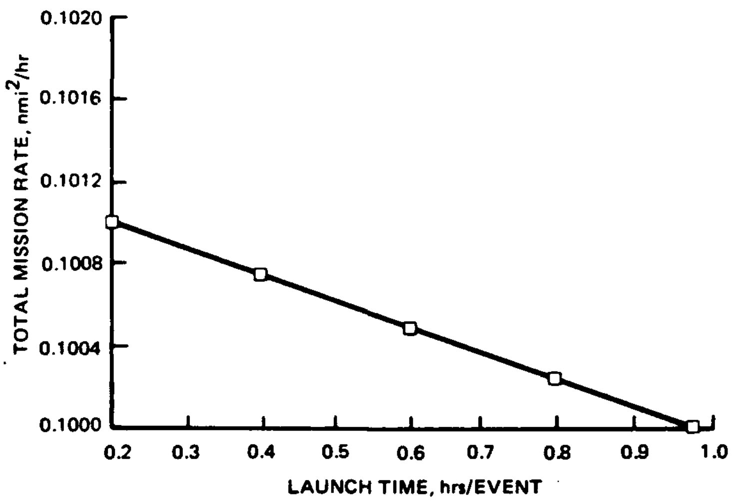

Figure 2. Baseline towed system deep scenario: total mission rate versus launch time.

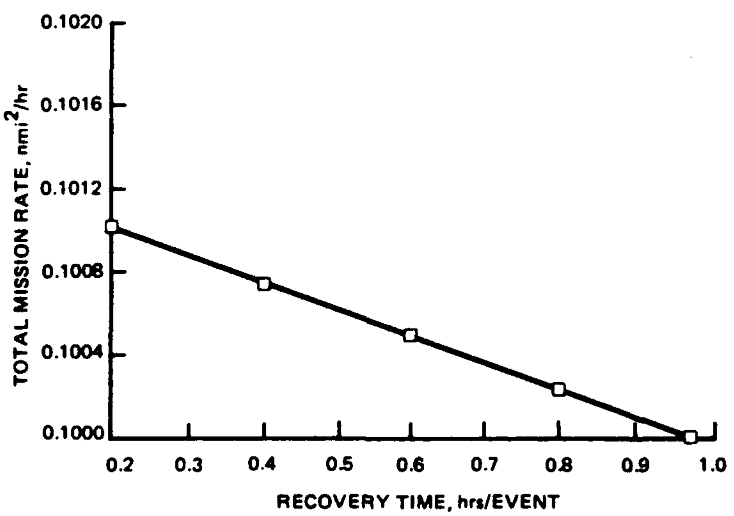

Figure 3. Baseline towed system deep scenario: total mission rate versus recovery time.

OPTIMIZATION STUDY

In the Sensitivity Analysis, the effect of each system variable on the search rates of a baseline towed system and a corresponding free-swimmer was determined. Only one variable at a time was examined, and each variable was examined over a broad range (from minimum capability to well beyond state-of-the-art). During the Optimization Study, more specific results were obtained. A state-of-the-art value was assigned to each system variable, and search rates for the baseline towed system and corresponding free-swimmer were obtained by *cumulatively* pushing each variable to its state-of-the-art value.* By doing so, the relative importance of pushing each value to its reasonable limit was readily obtained.

BASELINE TOWED SYSTEM RESULTS

The first step of the Optimization Study was to assign state-of-the-art values to each system variable. These values and the rationale for selecting them appear in Table 3. The same values, superimposed on selected Sensitivity Analysis curves, appear in Figures 4 through 24.

The complete results of the state-of-the-art changes are summarized in Table 4. Note that the mission rates are cumulative. That is, the (deep scenario) mission rate of 0.2715 square nautical mile per hour in the navigation error row corresponds to a navigation error of 15 feet, a control error of 200 feet, *and* a launch time of 0.25 hours. The order was such that the least significant changes (to the baseline) would be effected first. Final results for the deep, middle, and shallow scenarios, respectively, were 0.9508, 1.4227, and 0.1154 square nautical miles per hour. These values represent improvements over the baseline values by factors of 5.77, 8.13, and 5.39.

Figures 25, 26, and 27 display the cumulative search rates obtained in the deep, middle, and shallow scenarios. The shaded portions of the bars indicate the contribution to the mission rates made by each improved system variable. Few surprises resulted: wherever there was a means of significantly improving a capability (such as speed in all cases, or vehicle control error in the deep and middle cases), that improved capability was a significant factor in the cumulative state-of-the-art mission rate.

*The term "state of the art" implies in this case that the hardware or technique has either been built or demonstrated. All components or techniques analyzed in this study were drawn from openly advertised or published sources.

Table 3. Baseline towed system state-of-the-art values.

System Variable	Baseline and State-of-the-Art (SOA) Values
Deck time	Baseline value: 1 hour SOA value: 1 hour Deck time is an insignificant portion of a towed system search. There was no rationale for and little to be gained by reducing it.
Recovery time	Baseline value: 0.5 hour SOA value: 0.5 hour There was no rationale for reducing the towed system recovery time.
Launch time	Baseline value: 0.5 hour SOA value: 0.25 hour Team members felt that launch time could be reduced to 15 minutes.
Ascent/descent rate	Baseline value: 12,000 feet/hour SOA value: 12,000 feet/hour The 12,000 feet/hour baseline rate for a standard cabled vehicle was considered sufficiently fast. A winch was located that will launch or retrieve a faired cable at an equivalent rate. Given that the baseline rate was fast and that ascent/descent rate has little impact on the towed mission rate, there was little to be gained by pushing the rate any further.
Evaluation turn time	Baseline value: 0 hours SOA value: 0 hours The baseline value, based on the assumption of a single, continuously spiraling turn, is as fast as one can get.
Search turn time	Baseline value: 2 hours in parallel path pattern. SOA value: 0 hours in rectangular spiral The state-of-the-art assumption is based on a rectangular spiral search with computer-aided 90-degree turns (the ship turns such that the fish follows the desired path). The Marine Physical Laboratory (MPL) of the Scripps Institute of Oceanography has tested such a system (SUPER TOAD).*

*"Computer Aided Piloting of a Deeply Towed Vehicle," by John D. Mudie, Marine Physical Laboratory, Scripps Institution of Oceanography.

Table 3. Baseline towed system state-of-the-art values (Continued).

System Variable	Baseline and State-of-the-Art (SOA) Values
Evaluation and search track overlap	Baseline value: 0.5 SOA value: Variable. For each scenario and phase, track overlap will be optimized after all other capabilities have been optimized.
Search and evaluation total detection probabilities (tactics)	Baseline value (each): 0.9 SOA value (each): 0.9 These were arbitrary choices not subject to "optimization." (Curves were linear; there was no "optimum" detection probability.)
Search and evaluation vehicle control error	Baseline values: deep: 600 feet middle: 600 feet shallow: 100 feet SOA value: deep: 200 feet middle: 200 feet shallow: 100 feet The SOA value (deep) was based on a control error achieved by MPL. No data was available with which to predict a better value for the shallow case.
Navigation error	Baseline value: AUSS calculated (about 60 feet at 20,000 feet) SOA value: 15 feet Manufacturers currently boast the 15-foot rms error. The 60-foot baseline is pessimistic because only two transponders are used in the AUSS model.
Evaluation (TV) swath detection probability	Baseline value: 1.0 SOA value: 1.0 1.0 is normally assigned to the optical viewing system.
False target density	No change from baseline values (0.13 per square nautical mile in deep and middle cases, 2.7 in shallow case). This is not a parameter that is "optimizable."
Search system swath	Baseline value: deep: 5310 feet middle: 5310 feet shallow: 330 feet SOA value: deep: 6995 feet middle: 6995 feet shallow: 330 feet

Table 3. Baseline towed system state-of-the-art values (Continued).

System Variable	Baseline and State-of-the-Art (SOA) Values
	The baseline values were predicted by the AUSS model based on specific baseline sonar parameters. The deep and middle SOA values were obtained by modeling an MPL SLS with no center gap (assumes FLS "fill in"). The baseline shallow swath (330 feet) exceeded that of the MPL sonar.
Search sensor detection probability	Baseline value: 0.9 SOA value: 0.9 These are typical numbers, with no method available of assuring a higher probability.
Evaluation (TV) swath width	Baseline value: 21.8 feet (all cases) SOA value: deep: 55 feet middle: 55 feet shallow: 30.2 feet SOA values are AUSS model predictions for the SIT camera.
Speed	Baseline value: 1.5 knots (all cases) SOA value: deep search: 6 knots deep evaluation: 6 knots middle search: 6 knots middle evaluation: 6 knots shallow search: 4.25 knots shallow evaluation: 7 knots All SOA values assume that a faired cable is used (drag coefficient, 0.13). The criterion for selecting viable operating speed was that the cable angle at the ship at the higher speed not exceed the angle for the 1.5 knot case (≈ 45 degrees). This criterion produced all the speeds listed except for the shallow search case, where sonar considerations limited the speed to 4.25 knots.

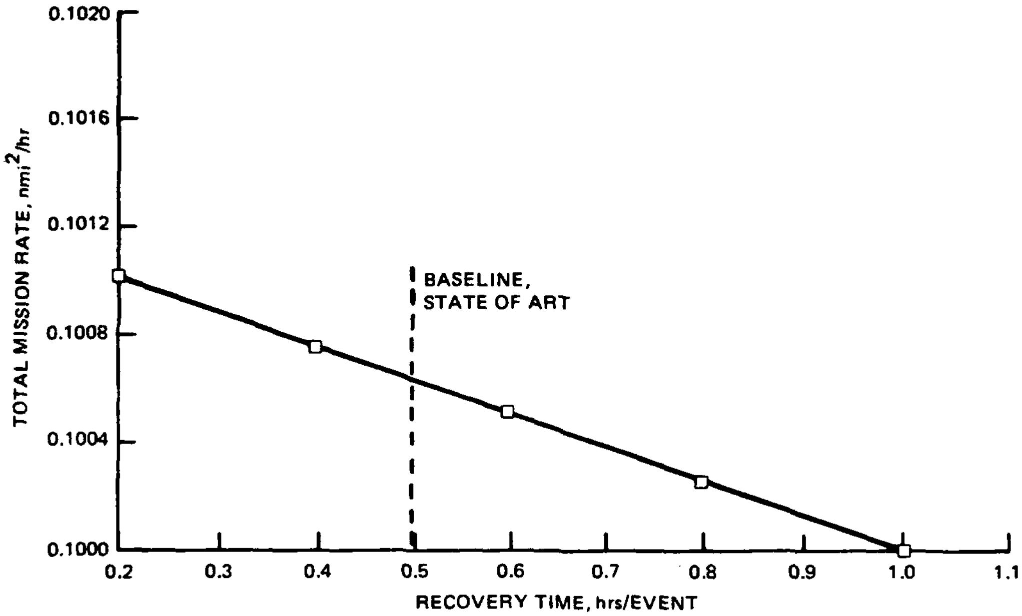

Figure 4. Recovery time sensitivity.

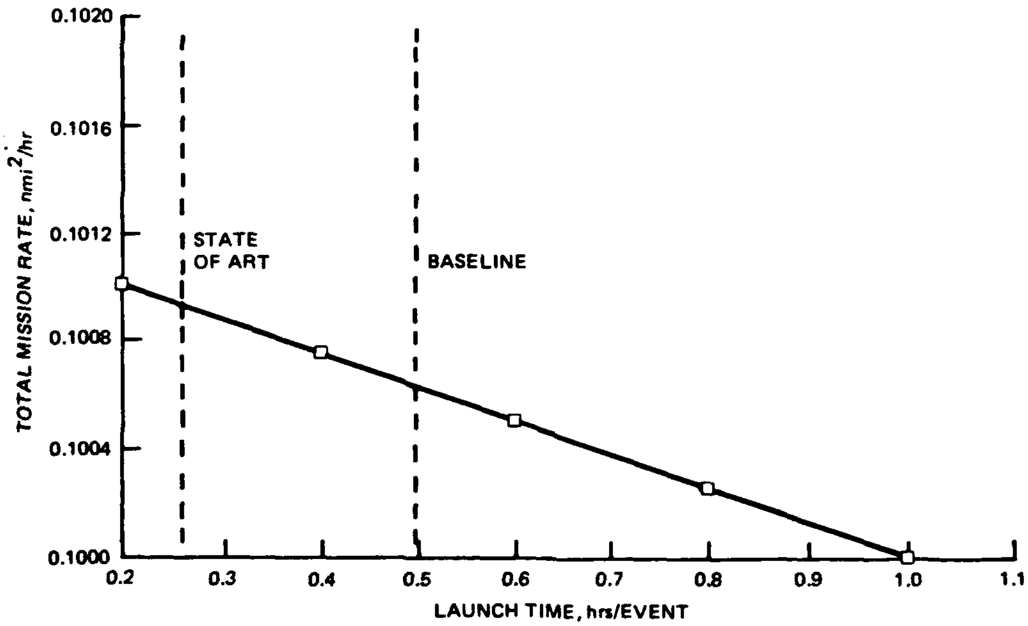

Figure 5. Launch time sensitivity.

Figures 4 and 5. Baseline Towed System Deep Scenario.

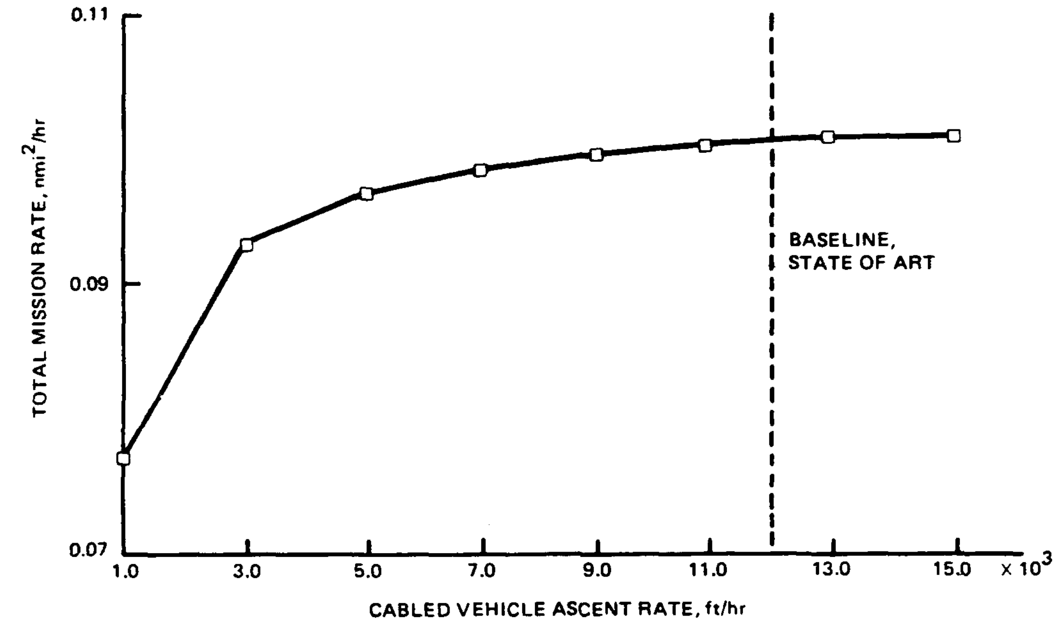

Figure 6. Cabled vehicle ascent rate sensitivity.

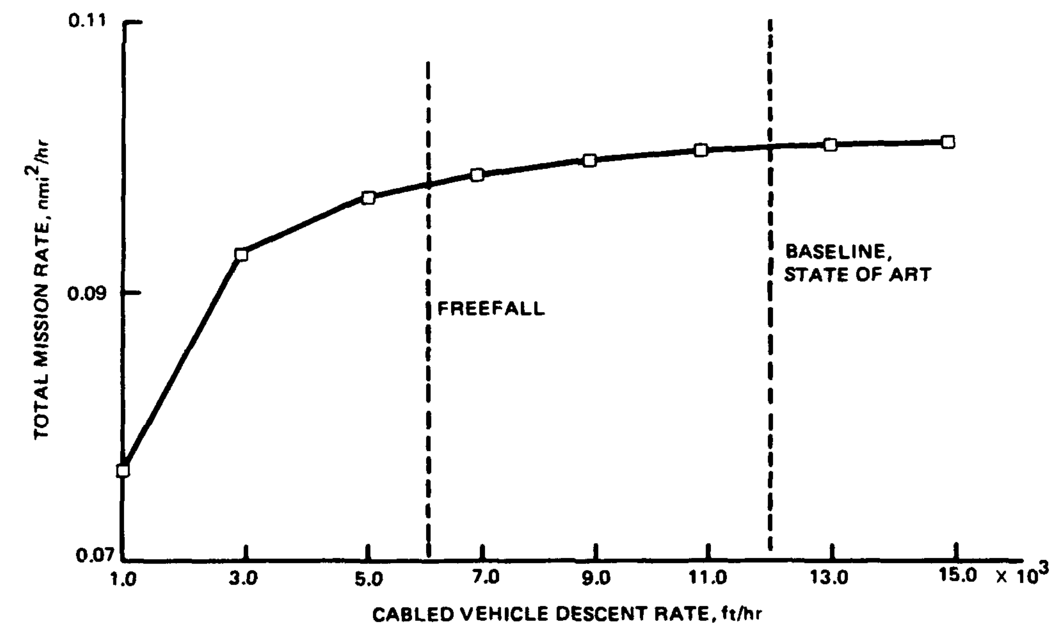

Figure 7. Cabled vehicle descent rate sensitivity.

Figures 6 and 7. Baseline Towed System Deep Scenario.

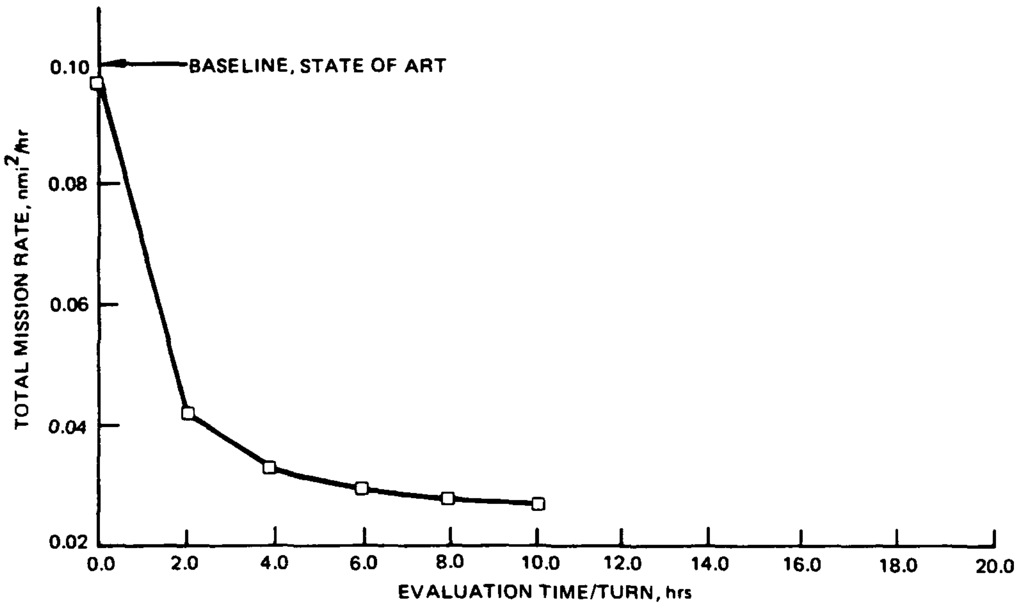

Figure 8. Evaluation time/turn sensitivity.

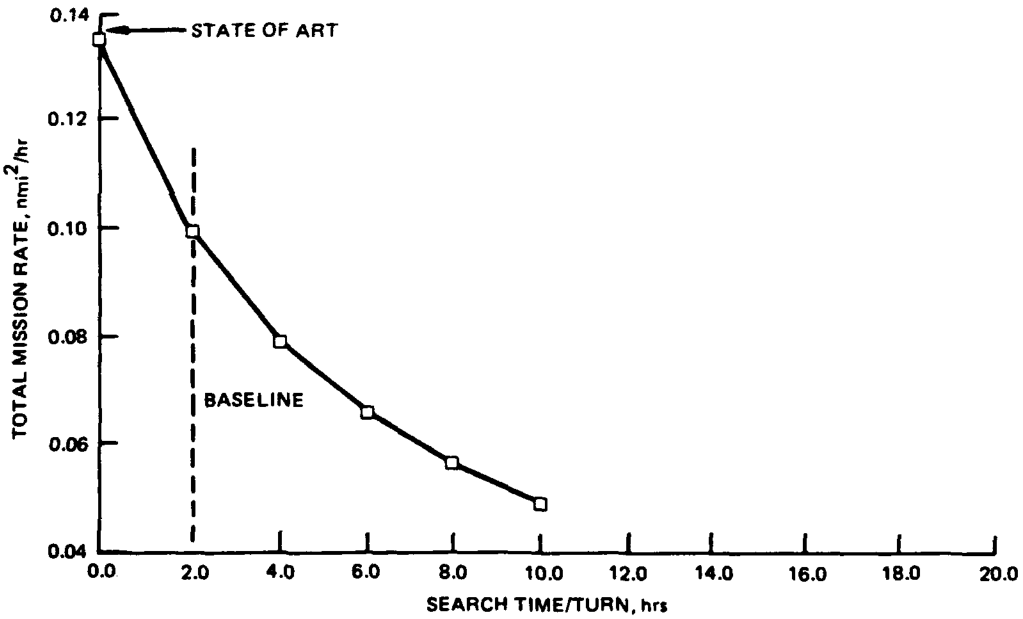

Figure 9. Search time/turn sensitivity.

Figures 8 and 9. Baseline Towed System Deep Scenario.

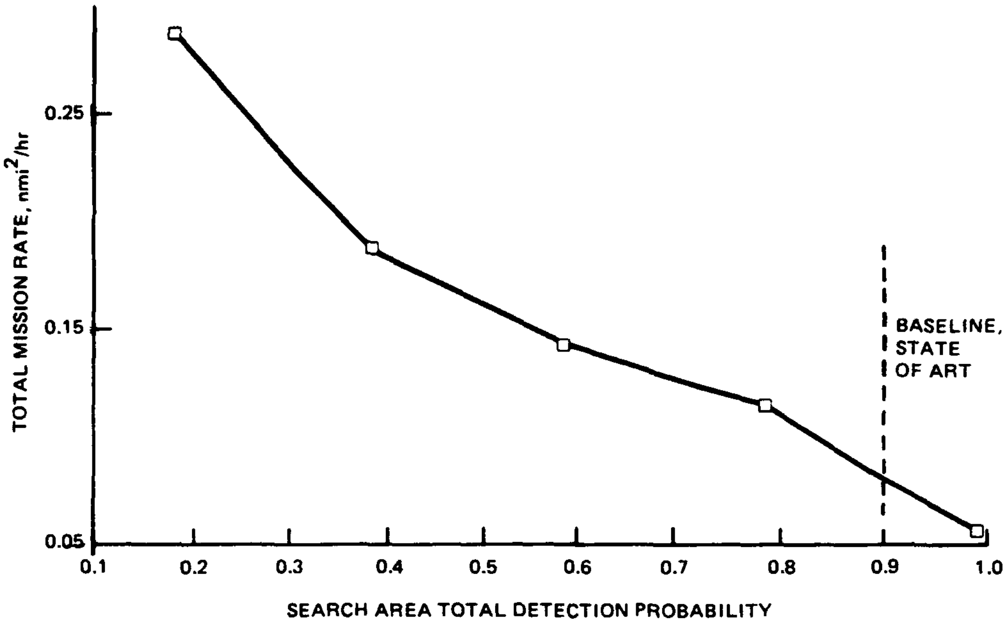

Figure 10. Search area total detection probability sensitivity.

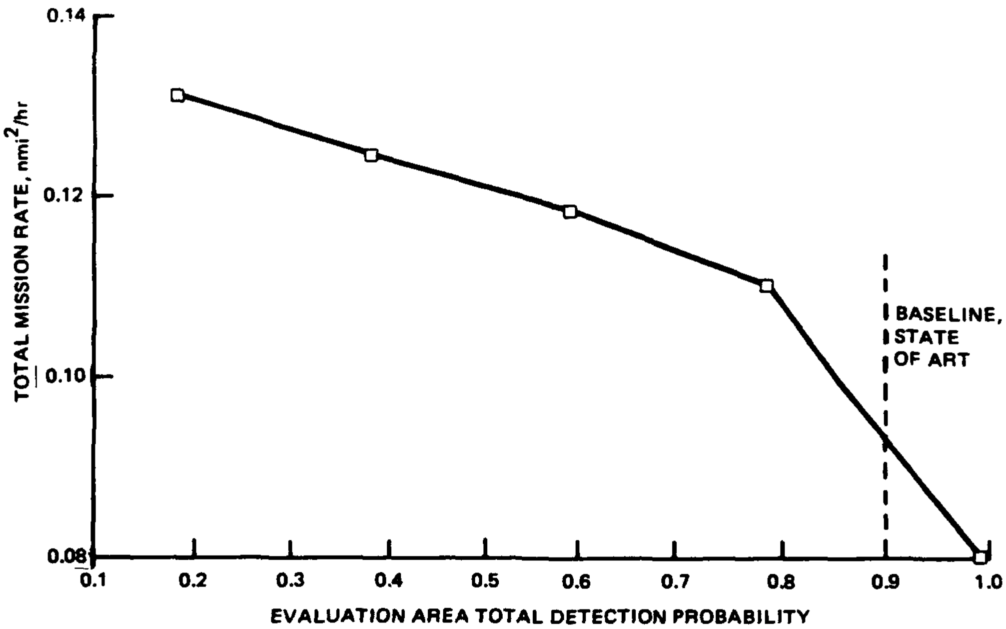

Figure 11. Evaluation area total detection probability sensitivity.

Figures 10 and 11. Baseline Towed System Deep Scenario.

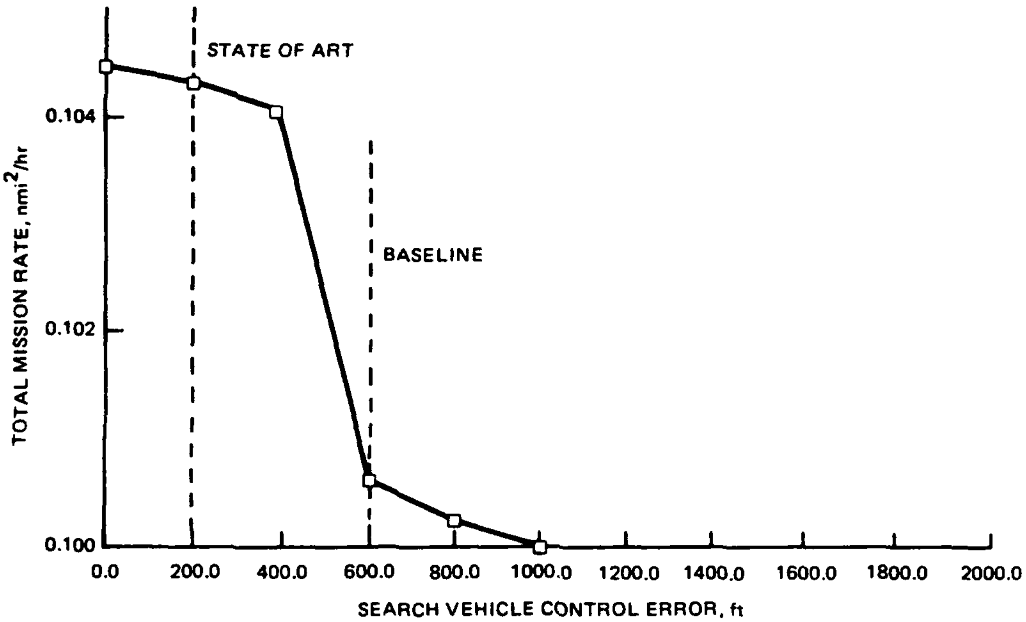

Figure 12. Search vehicle control error sensitivity.

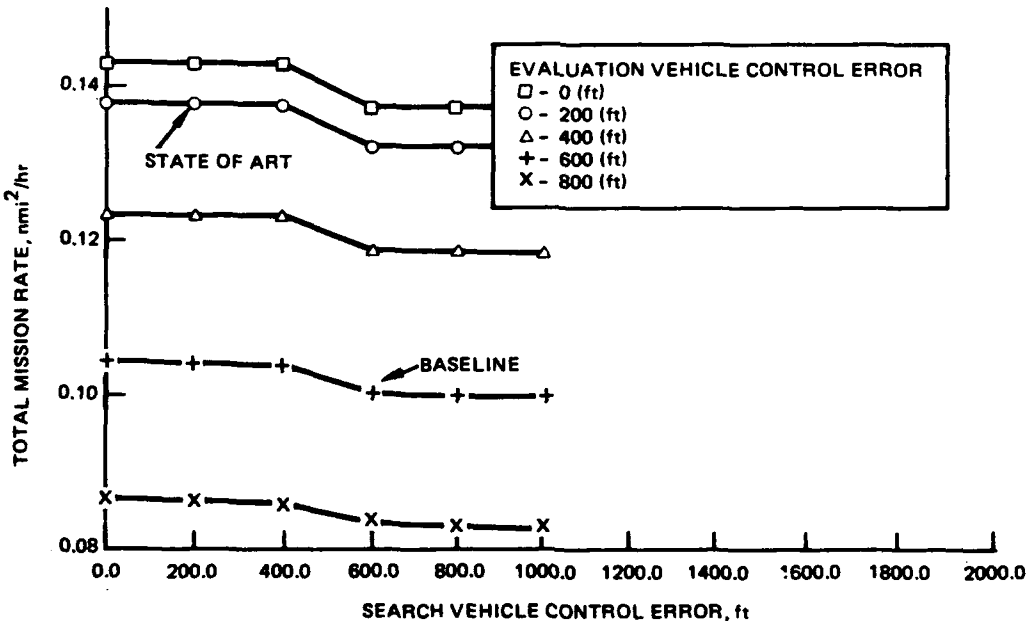

Figure 13. Search vehicle control error sensitivity.

Figures 12 and 13. Baseline Towed System Deep Scenario.

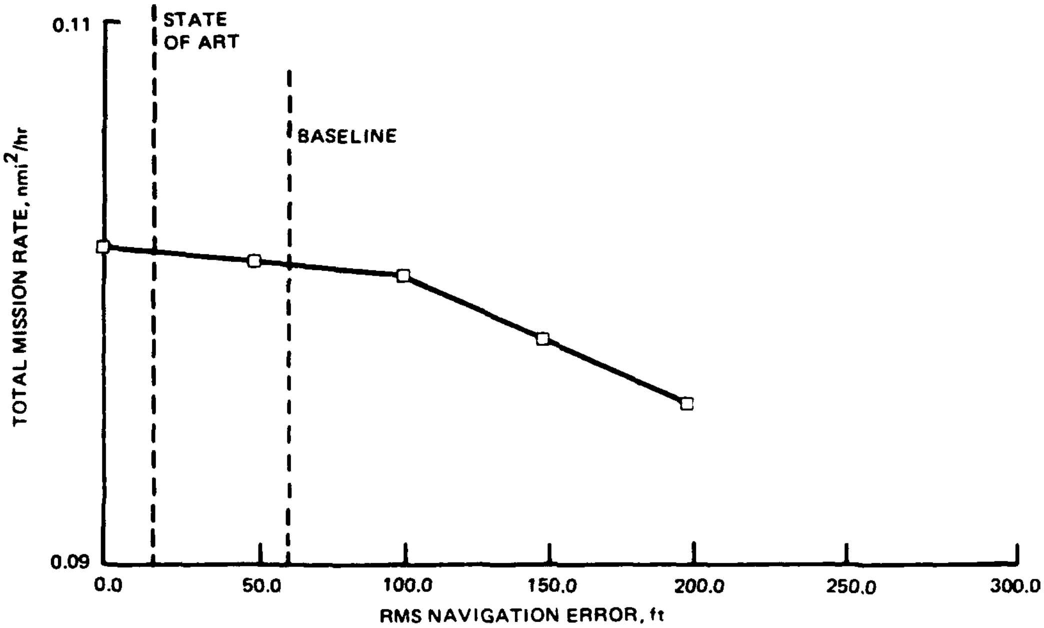

Figure 14. Rms navigation error sensitivity.

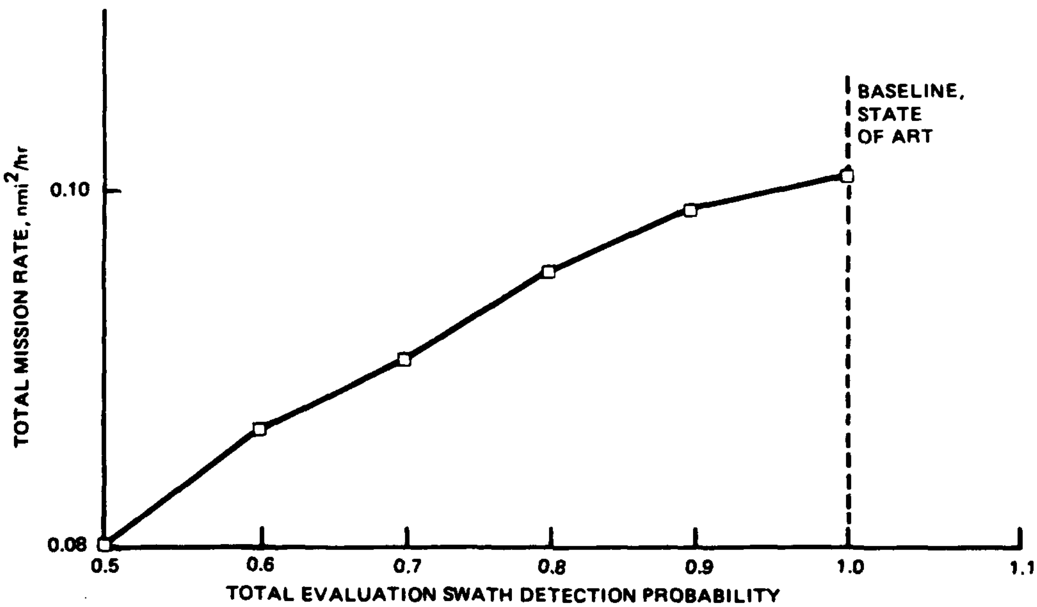

Figure 15. Total evaluation swath detection probability sensitivity.

Figures 14 and 15. Baseline Towed System Deep Scenario.

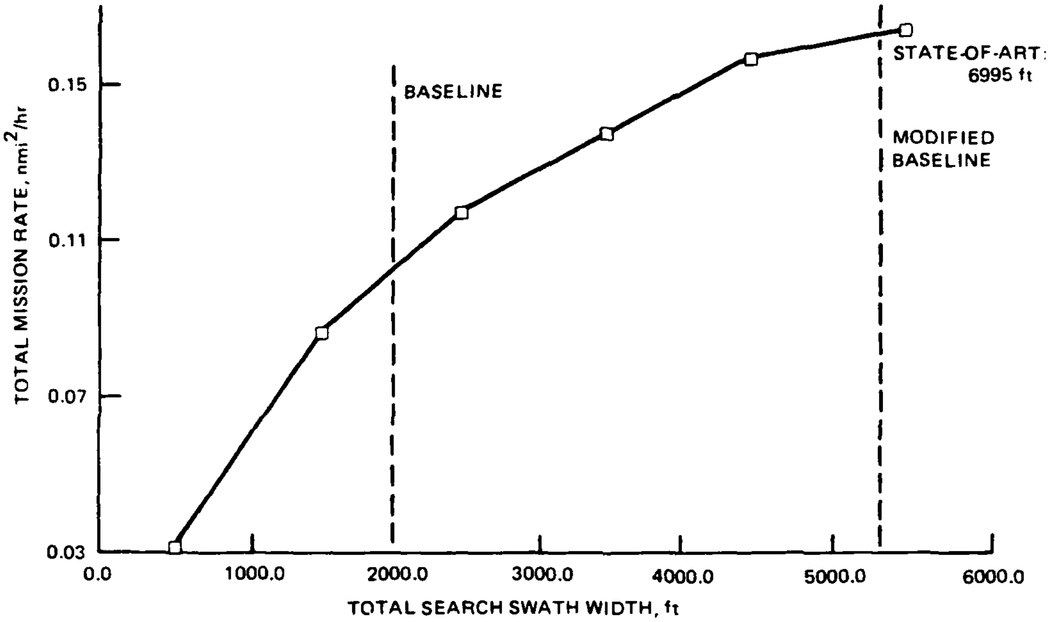

Figure 16. Total search swath width sensitivity

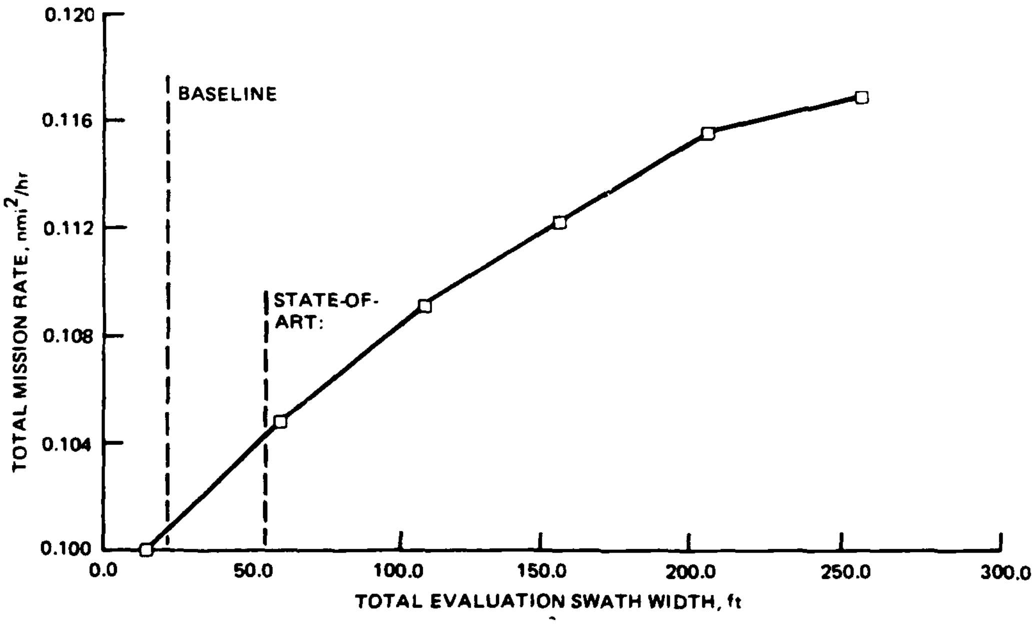

Figure 17. Total evaluation swath width sensitivity.

Figures 16 and 17. Baseline Towed System Deep Scenario.

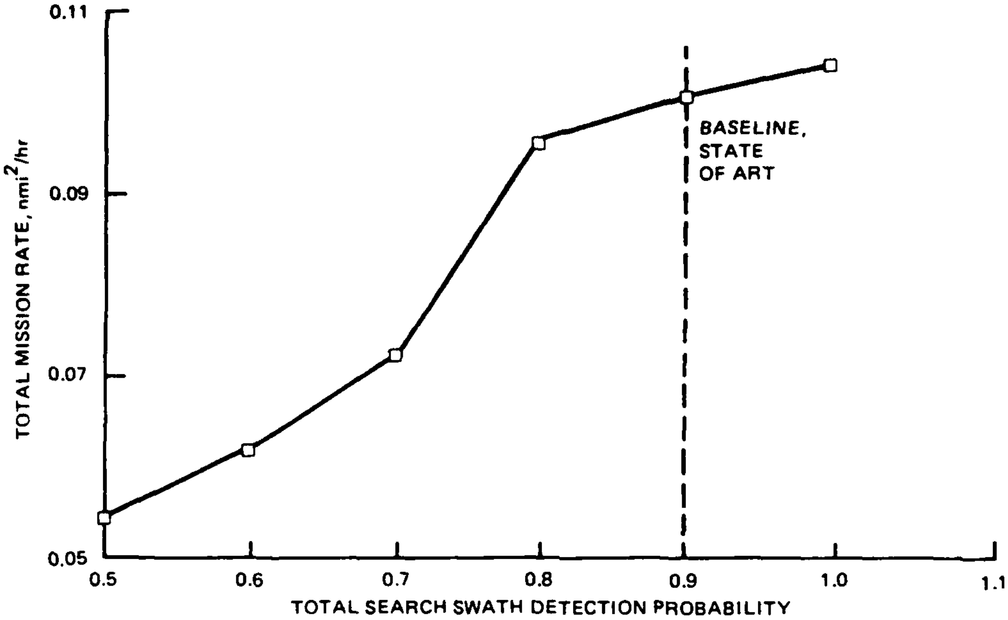

Figure 18. Total search swath detection probability sensitivity

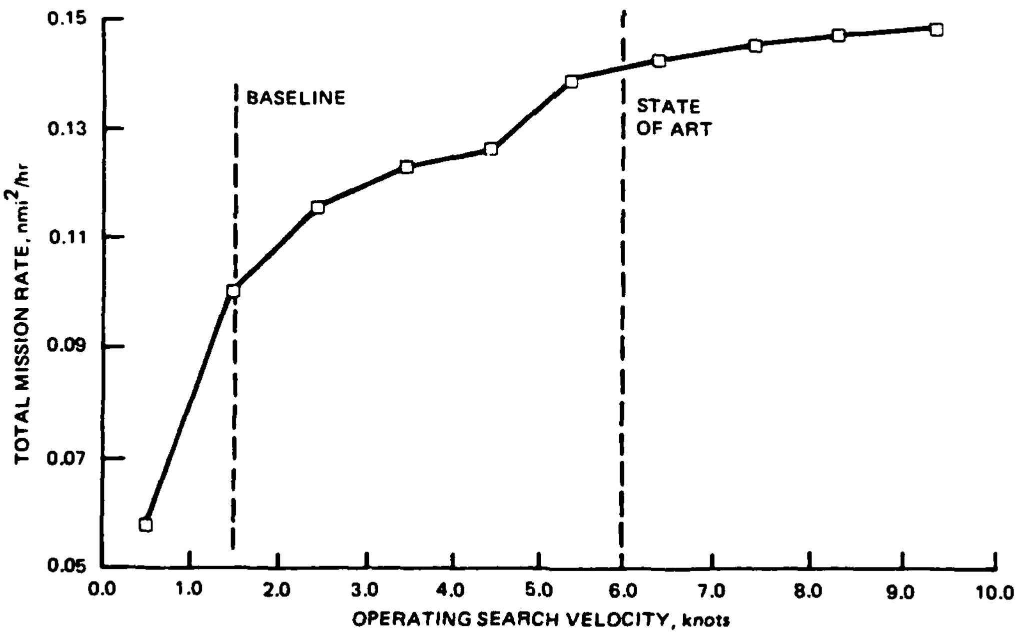

Figure 19. Operating search velocity sensitivity.

Figures 18 and 19. Baseline Towed System Deep Scenario.

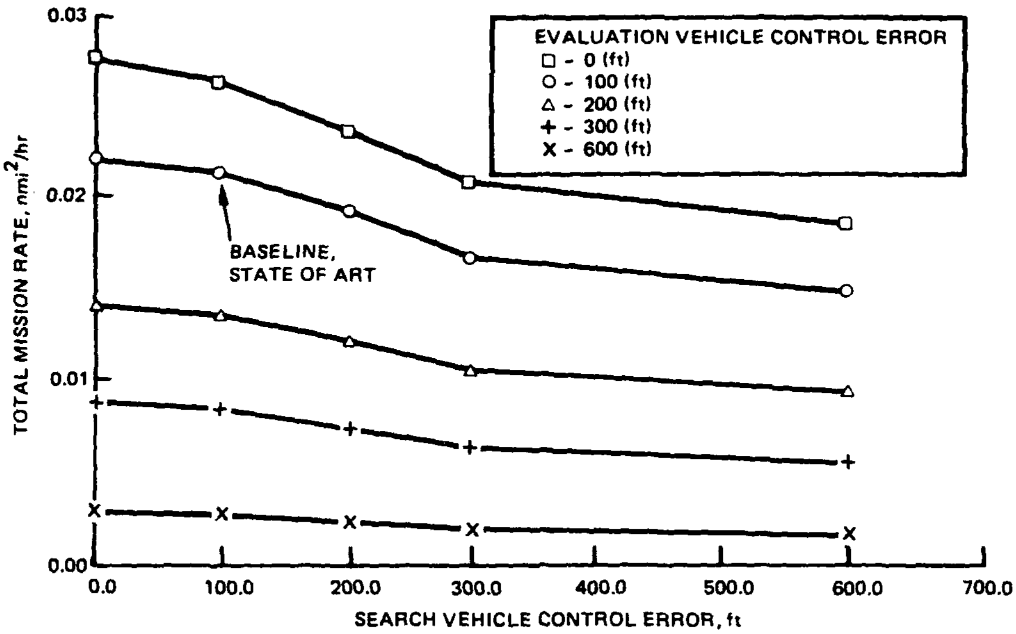

Figure 20. Search vehicle control error sensitivity.

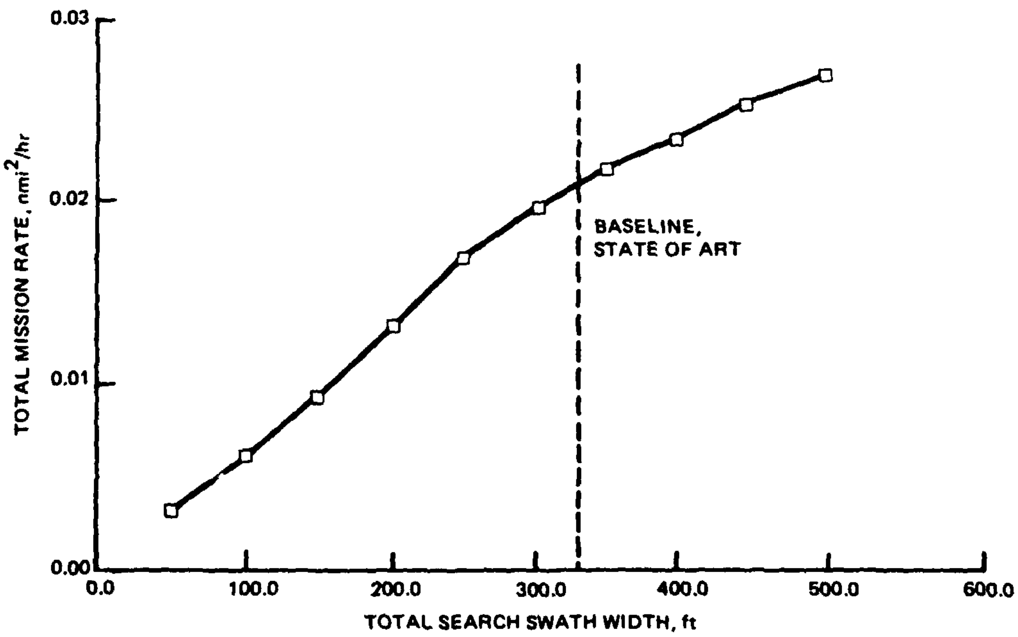

Figure 21. Total search swath width sensitivity.

Figures 20 and 21. Baseline Towed System Shallow Scenario.

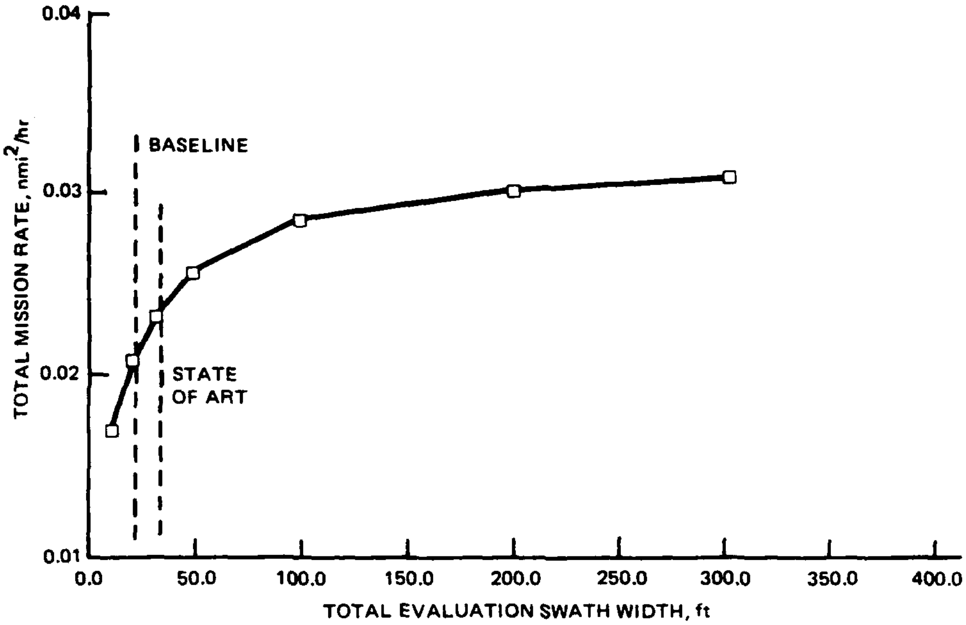

Figure 22. Total evaluation swath width sensitivity.

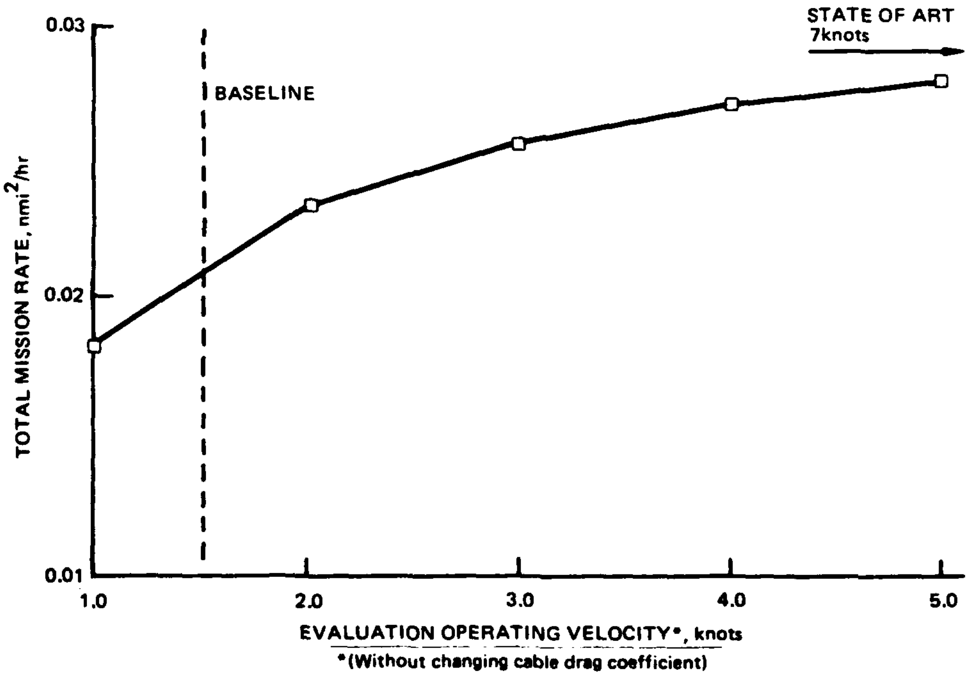

Figure 23. Evaluation operating velocity sensitivity.

Figures 22 and 23. Baseline Towed System Shallow Scenario.

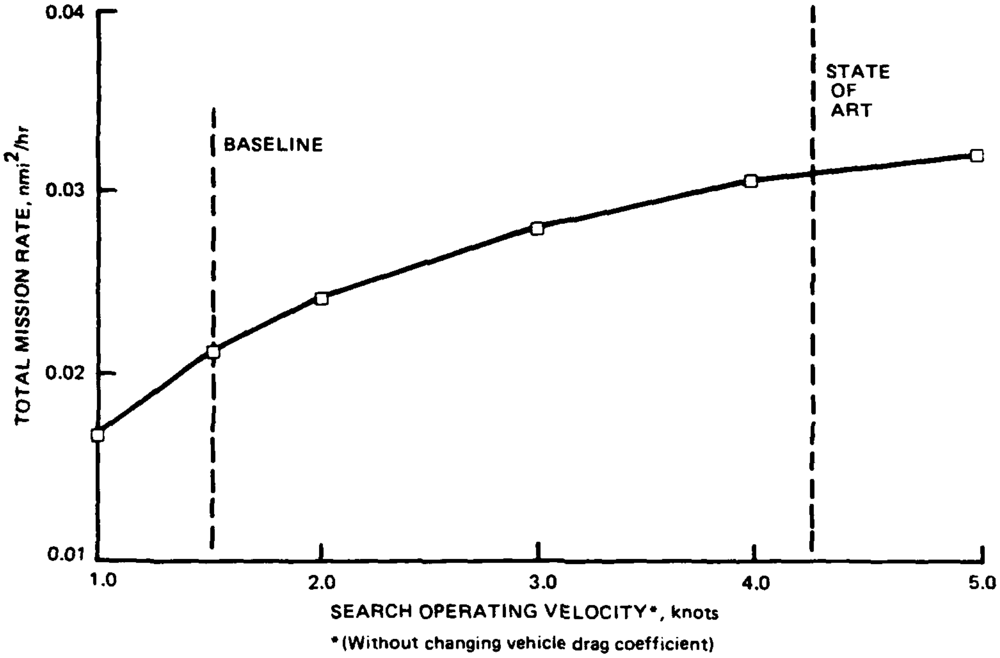

Figure 24. Search operating velocity sensitivity.

Figure 24. Baseline Towed System Shallow Scenario.

Table 4. Optimized state-of-the-art towed system results.

Variable	Deep Scenario (Baseline Mission Rate: 0.1649)			Middle Scenario (Baseline Mission Rate: 0.175)			Shallow Scenario (Baseline Mission Rate: 0.0214)		
	Baseline Value	State-Of-Art Value	Cumulative Mission Rate, nmi^2/hr	Baseline Value	State-Of-Art Value	Cumulative Mission Rate, nmi^2/hr	Baseline Value	State-Of-Art Value	Cumulative Mission Rate, nmi^2/hr
Launch time, hours	0.5	0.25	0.1657	0.5	0.25	0.1759	0.5	0.25	0.0214
Search control error, feet	600	200		600	200		100	100	
Evaluation control error, feet	600	200	0.269	600	200	0.269	100	100	0.0214
Navigation rms Error, feet	(≈ 60)	15	0.2715	(≈ 60)	15	0.2979	(≈ 60)	15	0.0252
Search Pattern	Parallel Path	Rect. Spiral		Parallel Path	Rect. Spiral		Parallel Path	Rect. Spiral	
Search turn time, hours	2	0	0.3907	2	0	0.4477	1	0	0.0302
TV Swath, feet	21.8	55		21.8	55		21.8	30.2	
TV height, feet	30.0	98	0.4001	30.0	98	0.4601	30.0	32.6	0.0325
Best sonar swath, feet	5310	6995		5310	6995		330	330	
Best sonar height, feet	542	132	0.4423	542	132	0.5168	33.7	33.7	0.0325
Towed cable (drag coefficient)	0.17	0.13	0.4681	1.7	0.13	0.5278	1.7	0.13	0.0325
Search speed, knots	1.5	6	0.7309	1.5	6	0.9321	1.5	4.25	0.0623
Evaluation speed, knots	1.5	6	0.8872	1.5	6	1.2851	1.5	7	0.1000
Search track overlap fraction	0.5	0.35	0.9443	0.5	0.35	1.4082	0.5	0.35	0.1128
Eval track overlap fraction	0.5	0.26	0.9508	0.5	0.26	1.4227	0.5	0.26	0.1154

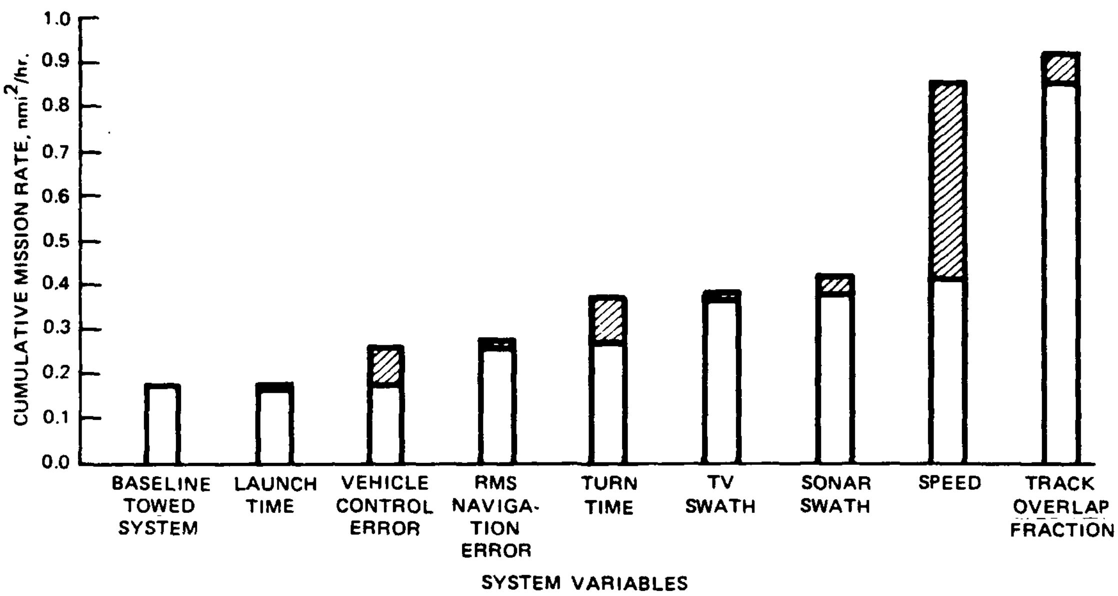

Figure 25. Cumulative mission rates obtained by pushing baseline towed system variables to state-of-the-art values, deep scenario.

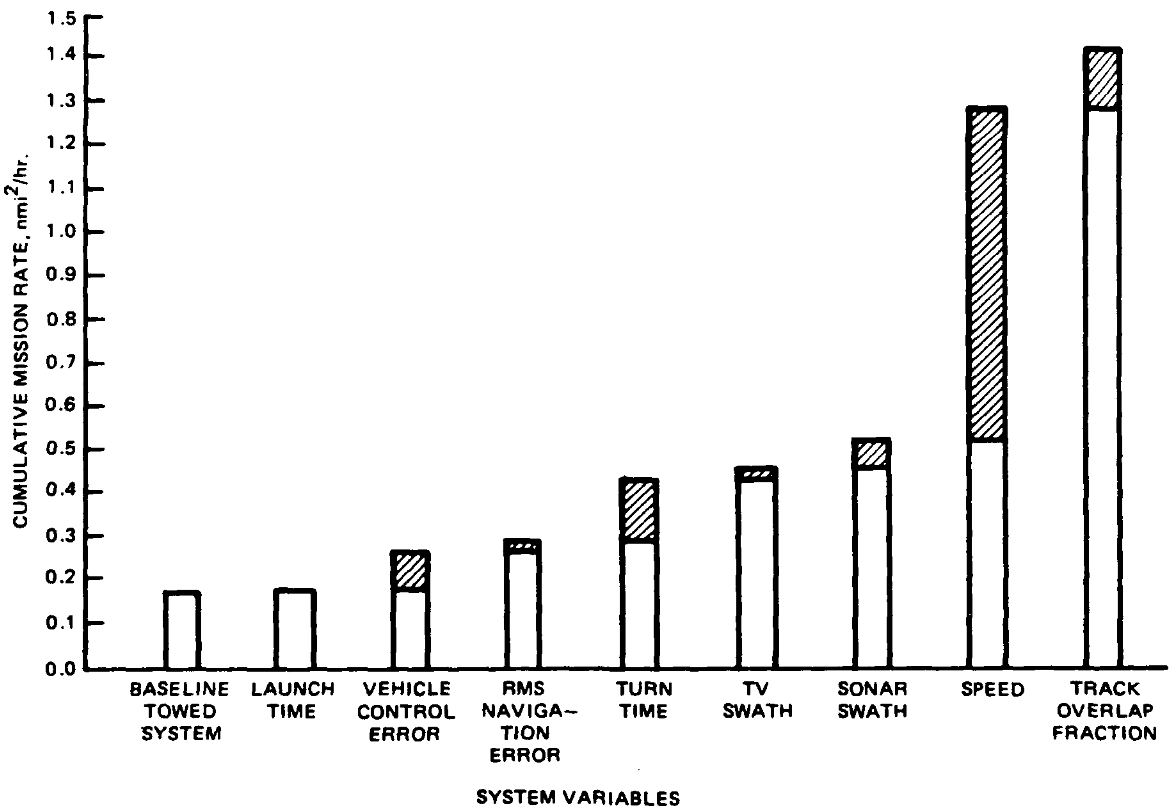

Figure 26. Cumulative mission rates obtained by pushing baseline towed system variables to state-of-the-art values, middle depth scenario.

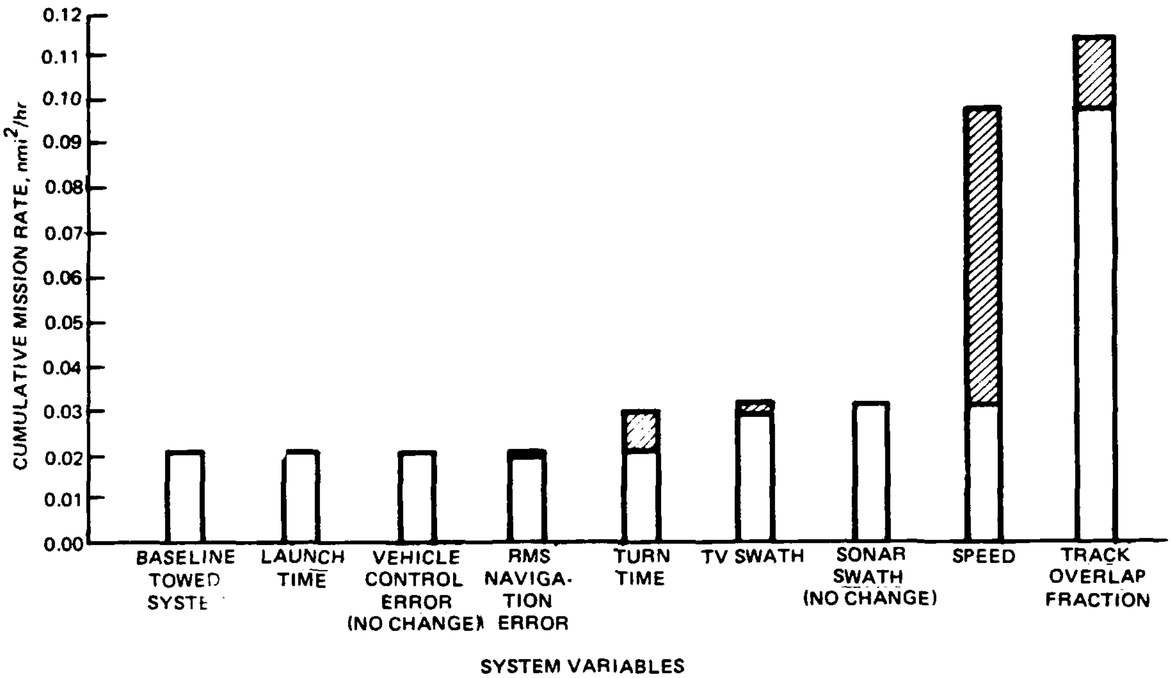

Figure 27. Cumulative mission rates obtained by pushing baseline towed system variables to state-of-the-art values, shallow scenario.

FREE-SWIMMER RESULTS

As with the towed system, the first step to optimizing the free swimmer performance was to assign a state-of-the-art value to each system variable. Most values were identical to those used for the towed system, with major differences occurring in the areas of speed and battery endurance.

Because the free-swimmer is not limited by cable drag, sensor limits dictate maximum vehicle speed. AUSS model predictions indicated that a 19-knot sonar speed was feasible in the deep scenarios, with only 4.25 knots available in the shallow scenario. (Refer again to Table 1 for the scenario descriptions. In this case, it is target length that exerts the dominant influence on sensor speed.) Although 19 knots is probably infeasible (at least, risky) with respect to considerations such as bottom following and navigation references, this value was used for this particular exercise in order to predict a "maximum" free-swimmer capability. Because only one bounce was required at this speed (battery life was sufficient for this one quick bounce), it was assumed that the video data could also be recorded at 19 knots and played back later at a slower rate. In the shallow case, where more than one bounce was necessary, the decision was made to play back the video data at the same rate it was recorded. This real-time limit was therefore invoked assuming that the data would be recorded in a sequence of frames, allowing 2 seconds per frame. Given the forward swath of the camera, a 6.74-knot speed was indicated.

The question of battery endurance raised an even more fundamental question. One approach to search is to blanket an entire area (broad-area sonar search) and then to go back and evaluate promising sonar contacts (contact evaluation with video). Using this approach, the optimum free-swimmer would use a sufficient number of batteries to perform the entire search phase before surfacing. One disadvantage here is that a "sufficient number of batteries" might entail an incredibly large vehicle. (One bizarre example that occurred during a separate analysis called for a three-billion pound vehicle!). A second disadvantage is that a significant amount of time (and corresponding battery usage) might be wasted. As an example, consider a broad-area search that requires 200 hours non-stop. (This isn't a far-fetched example: The total search and evaluation time for the baseline towed system-shallow scenario mission in the Sensitivity Analysis was 467 hours.) Suppose that the target had been detected, on sonar, in the first hour. It would be over a week later before that contact would have been evaluated, or the object "found." Surely, there must be some median approach, some compromise between immediate contact evaluation and this search first - evaluate later approach. A complete examination of this question appears in Appendix C. The solution involves minimizing the mean time to find the target by dividing the search cell into an optimum number of subcells. Each subcell is both searched *and* evaluated before progressing to the next subcell. Applying this solution to the current free-swimmer case, a battery endurance of 7.7 hours resulted. Using lithium batteries, this endurance indicated a vehicle of less than 2000 pounds.

Table 5 summarizes the state-of-the-art values and the corresponding cumulative mission rates for the deep and shallow scenarios. The deep mission rates are "clock time" rates. (The entire area was searched to a detection probability of 0.9, and then all sonar contacts were evaluated.) The shallow mission rates are mean time rates. (It was assumed that one pass would be sufficient, and the quantity "$\bar{T}$" of Appendix C was optimized; it is these values of $\bar{T}$ that appear as the shallow scenario mission rates.) Figures 28 and 29 display these cumulative rates. The shaded portions of the bars indicate the contribution to the mission rates made by each system variable. As with the towed system, few surprises resulted. If a capability could be significantly improved (such as speed), the improvement had a significant impact on the mission rate.

Table 5. Optimized State-Of-The-Art Free-Swimmer Results.

Variable	Deep Scenario (Baseline Mission Rate: 0.8759)			Shallow Scenario (Baseline Mean Time Mission Rate: 0.1099)		
	Baseline Value	State-of the-Art Value	Cumulative Mission Rate, nmi^2/hr	Baseline Value	State-of the-Art Value	Cumulative Mission Rate, nmi^2/hr
Launch time, hours	0.5	0.25	0.8938	0.5	0.25	0.1188
Navigation rms error, feet	(≈60)	15	0.9089	(≈60)	15	0.1373
Search pattern	Parallel path	Rect. spiral		Parallel path	Rect. spiral	
Search turn time	Calculated	0		Calculated	0	
Evaluation pattern	Rect. spiral	Rect. spiral		Rect. spiral	Rect. spiral	
Evaluation turn time	Calculated	0	1.0102	Calculated	0	0.1392
TV swath, feet	21.8	55		21.8	30.2	
TV height, feet	30.0	98	1.0102	30.0	32.6	0.1395
Sonar swath, feet	5310	6995		330	330	
Sonar height, feet	542	132	1.091	33.7	33.7	0.1395
Search track overlap fraction				0.5	0.1	
Evaluation track overlap fraction				0.5	0.5	0.2023
Battery endurance, hours	5	1.8		5	7.7	
Search speed, knots	5	19	3.2719	4.25/6.74	4.25/6.74	0.2170
Search track overlap fraction	0.5	0.35	3.5288			
Evaluation track overlap fraction	0.5	0.8	3.5306			

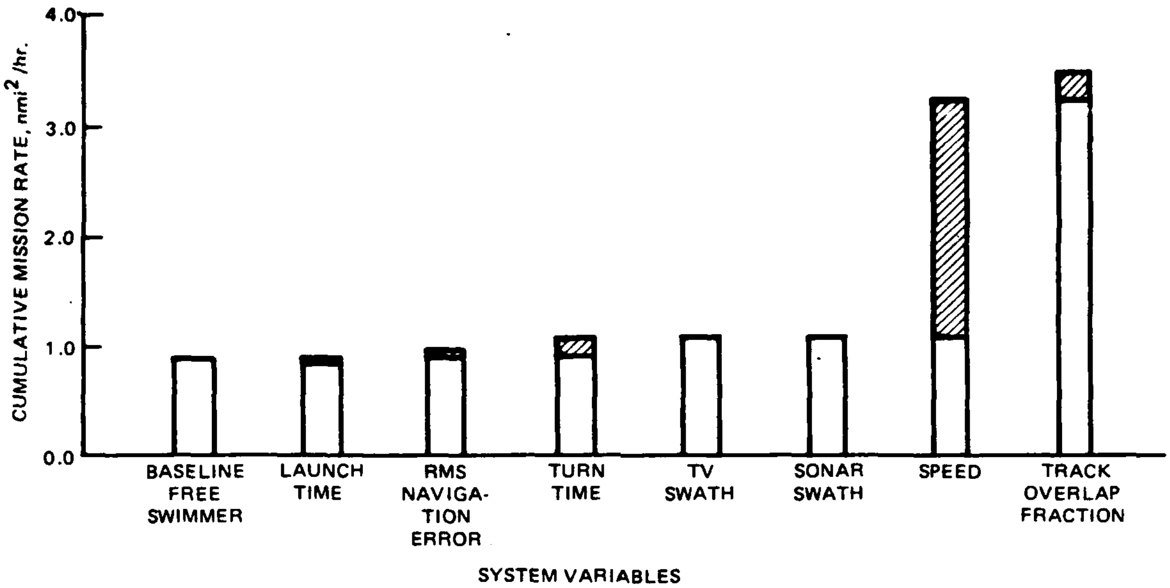

Figure 28. Cumulative mission rates obtained by pushing free-swimmer system variables to state-of-the-art values, deep scenario.

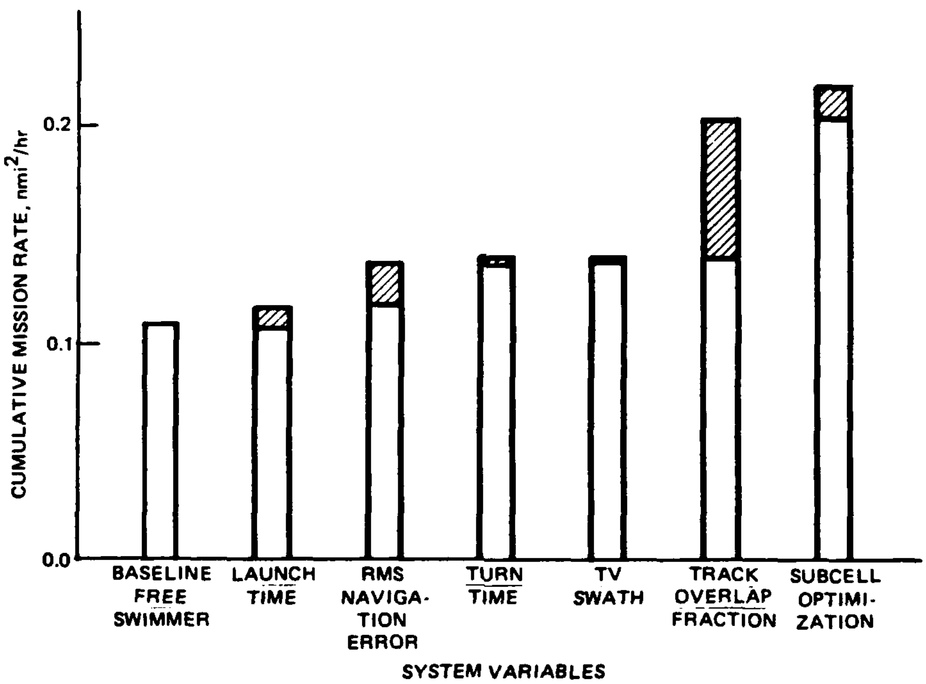

Figure 29. Cumulative mean time mission rates obtained by pushing free-swimmer system variables to state-of-the-art values, shallow scenario.

DEVELOPMENT OF CANDIDATE SYSTEMS

Approximately thirty system concepts were proposed and considered in a series of engineering evaluation sessions, of which seven were selected as promising enough to warrant an extensive performance analysis. Criteria for selection included:

(1) The system should (on inspection) offer a significant improvement in mission rate over the baseline towed system rate.

(2) The system should consist of off-the-shelf or at least feasible (previously demonstrated or tested) technology; long-term development items were prohibited.

Systems excluded from analysis for nonconformance to one or both of the above criteria are listed in Appendix E (Table E-9).

Figures 30 through 38 illustrate the seven proposed systems. Relative to the baseline-towed systems, all of the systems feature a smaller vehicle control error (for towed systems, 200 feet in the deep case as opposed to the 600-foot baseline value; with no change in the shallow case; control error is assumed to be 0 feet for free-swimmers), more precise navigation (15 feet rms error as opposed to the baseline error of approximately 60 feet), and a slightly shorter launch time (15 minutes as opposed to the baseline 30 minutes). These features offered only slight improvements in the mission rates; more significant features are discussed below as a function of each system.

OPTIMIZED TOWED SYSTEM

The system illustrated in Figure 30 is essentially the same as the baseline towed system, with two major exceptions: (1) higher speeds are possible by using a faired cable, and (2) turn times are reduced to 0 by using a rectangular spiral search pattern with computer-aided ship turns (computer-aided ship navigation is used to keep the vehicle on an exact track).

TOWED SYSTEM WITH DECOUPLING CLUMP

All of the above features are incorporated, with the addition of the following: (1) the vehicle is decoupled from the faired tow cable via a depresser clump in order to reduce vehicle control error; the vehicle maneuvers itself in the search phase via control surfaces (Figure 31); and (2) in the evaluation phase, the vehicle maneuvers via an active thruster; it is guided to the target via a scanning sonar mounted beneath the depresser clump (Figure 32). This latter feature reduces navigation error to 0 during final approach. The active thruster mode also offers a controlled inspection capability.

TOWED SYSTEM WITH TRAILER VIDEO

All of the above features are incorporated, with the addition of a small, laterally mobile vehicle with video/photographic capability (Figure 33). This vehicle trails behind the primary sonar vehicle, translating from side to side so that it flies over promising sonar contacts moments after they appear on the sonar screen. In essence, immediate contact evaluation is performed, with no time penalties, assuming that the sonar swath is relatively narrow. For larger sonar swaths, where the geometry of the situation prohibits complete video coverage of all sonar contacts, the trailing video vehicle will still scrutinize *some* of the sonar contacts, reducing the number required to examine during a classic contact

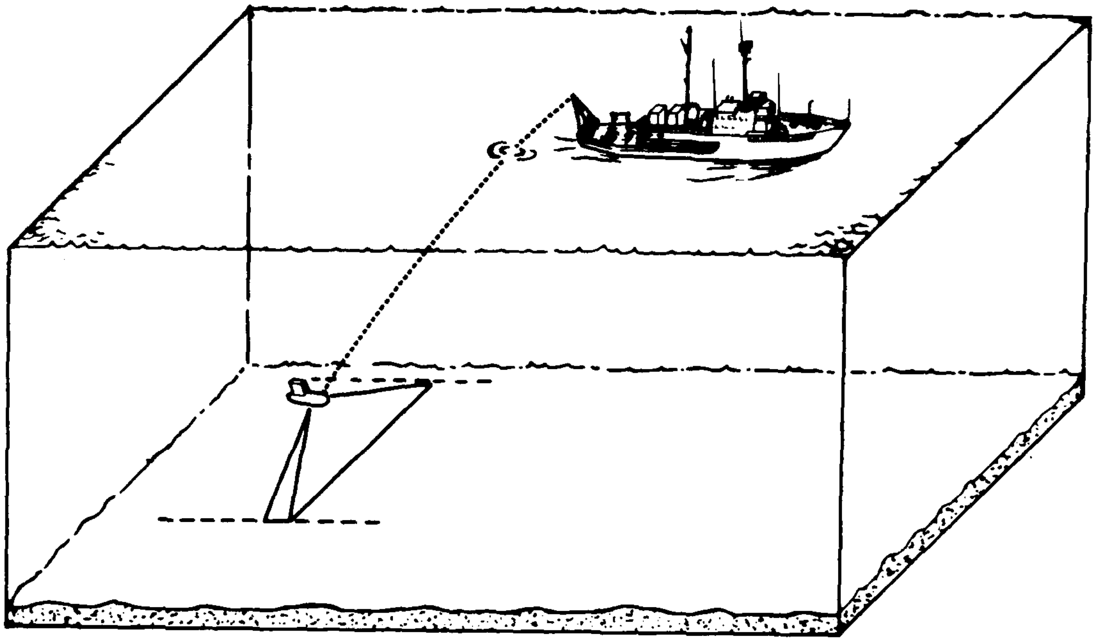

Figure 30. Optimized towed system.

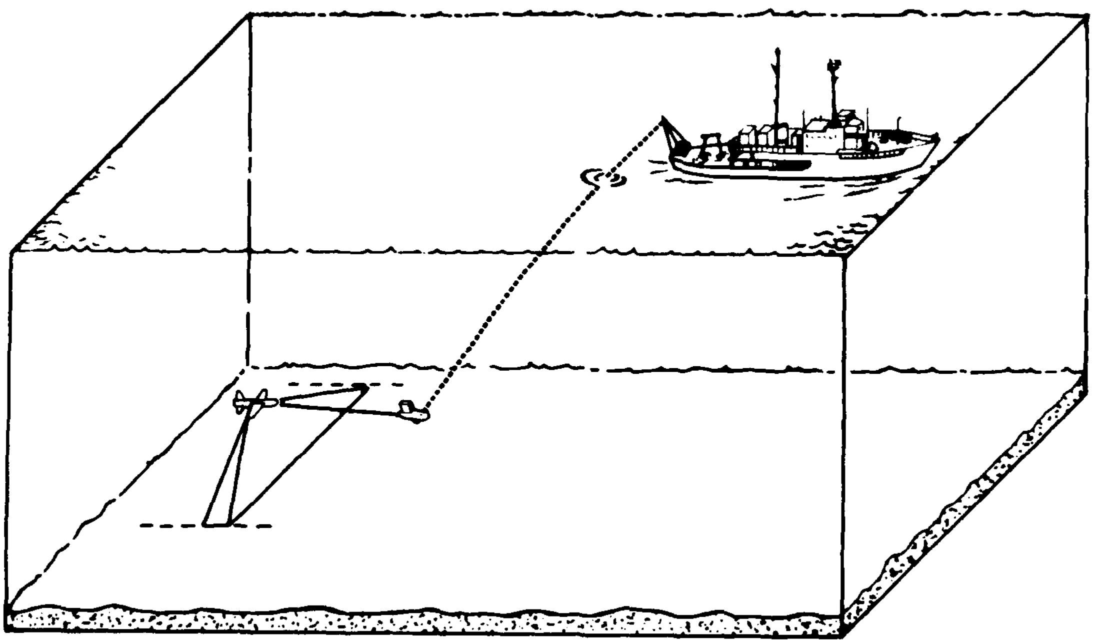

Figure 31. Towed system with decoupling clump (search phase).

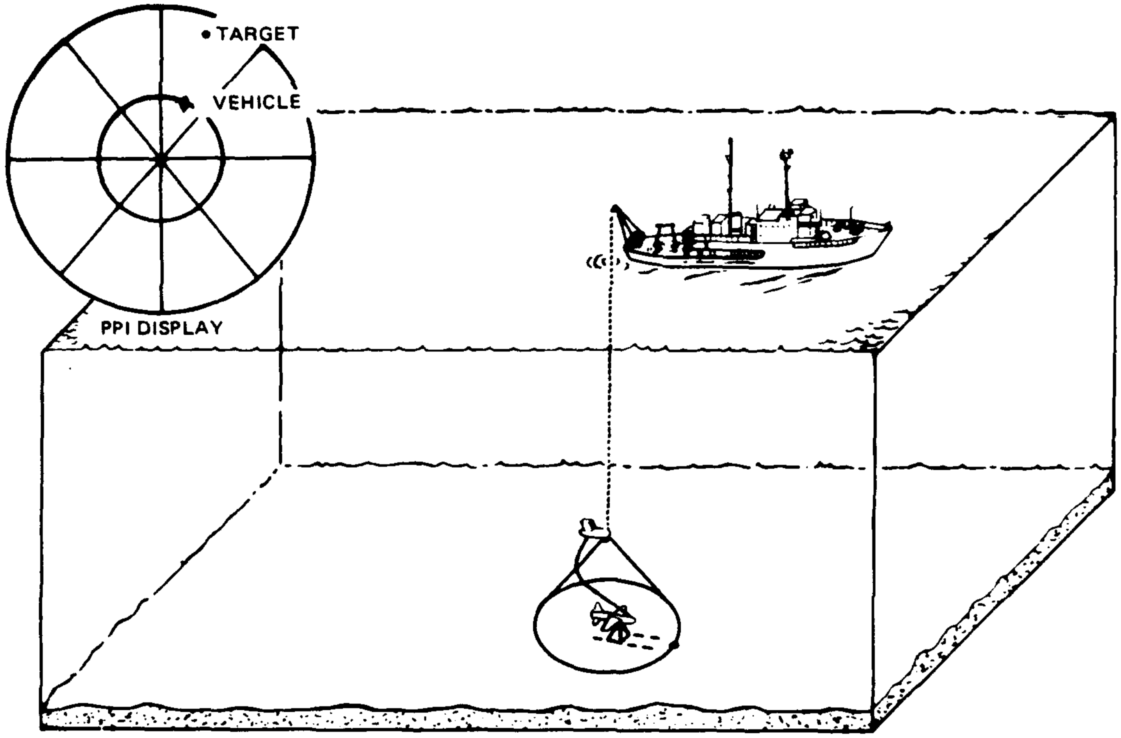

Figure 32. Towed system with decoupling clump (evaluation phase).

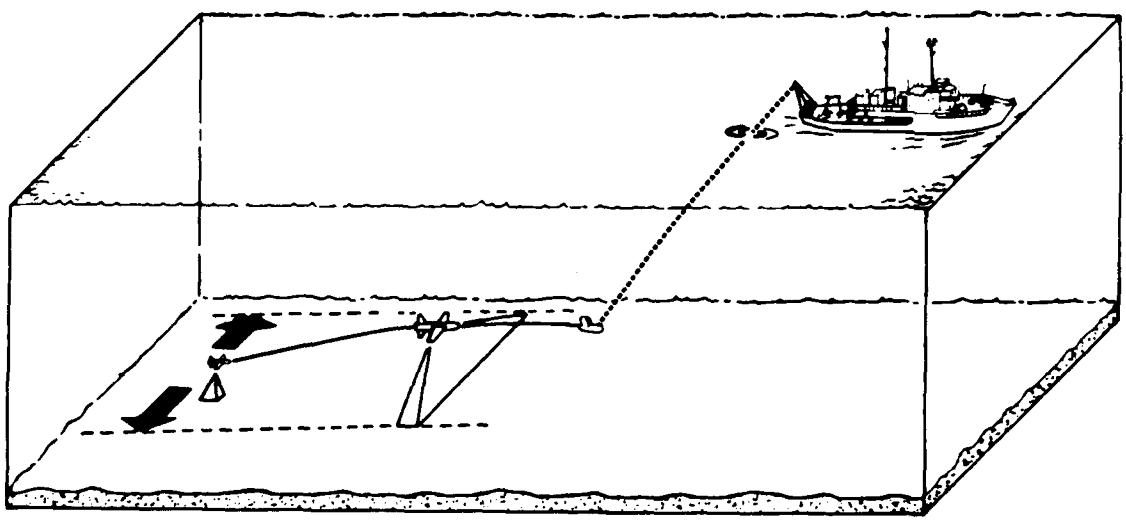

Figure 33. Towed system with trailer video (search/immediate contact evaluation phase).

evaluation phase. During formal contact evaluation (Figure 34), the video vehicle will perform its task under scanning sonar navigation, as per the previous system concept.

RF TETHER LINK/CURV TYPE SEARCH

The rf tether link vehicle (Figure 35) offers a compromise between a free-swimmer and a cabled vehicle. The vehicle, with a self-contained energy source, is hard-wire linked to a floating buoy that is in turn rf linked to the surface ship. The hard-wire link is light, inexpensive torpedo wire that pays out from the tail of the vehicle and which is left behind on the bottom. This link is capable of transmitting real-time sonar data and slow-scan video data. The search technique is similar to that used by NOSC's CURV vehicles. The vehicle transits to a given spot (via a bottom-mounted transponder net reference), hovers, and searches with a scanning sonar. Any promising contacts within the radius of the scan are immediately evaluated. Several advantages are offered by this concept:

(1) There are no special ship requirements;

(2) The cable, which pays out freely from the vehicle, introduces none of the forces on the vehicle that towing cables do, thus reducing vehicle control error to 0;

(3) Because the vehicle hovers during its sonar scan, there is no possibility of acoustic interference (from thrusters, flow noise, etc.) with sonar data;

(4) Sonar range scales can be adjusted, on scene, for viewing the same contacts with different resolutions;

(5) Because data is not transmitted while the vehicle transits from the center of one scan radius to the center of the next, and because there is no need to bottom follow during transit, and also because there is no cable drag, the transit can be conducted at high speeds;

(6) Navigation requirements are reduced, as it is only necessary to overlap the scan circles by a reasonable amount; and

(7) There are no navigation requirements during contact evaluation (the vehicle homes in on the targets via its scanning sonar).

FREE-SWIMMER

The usual free-swimmer operational mode (Figure 36) is to record side-look sonar data, examine it after recovering the vehicle, and then to launch the vehicle again for contact evaluation. This data, either on video tape or photographic film, must also be inspected after recovery. High energy density batteries are proposed to maximize bottom times. Advantages of the free-swimmer include the absence of special ship requirements and the elimination of cable-induced vehicle control error.

ACOUSTIC LINK FREE-SWIMMER

The acoustic link free-swimmer (Figure 37) combines the basic advantages of a free-swimmer with a real-time data/control link. Although speeds are limited to acoustic link rates (minimized real-time sonar data or slow-scan video data), available speeds are

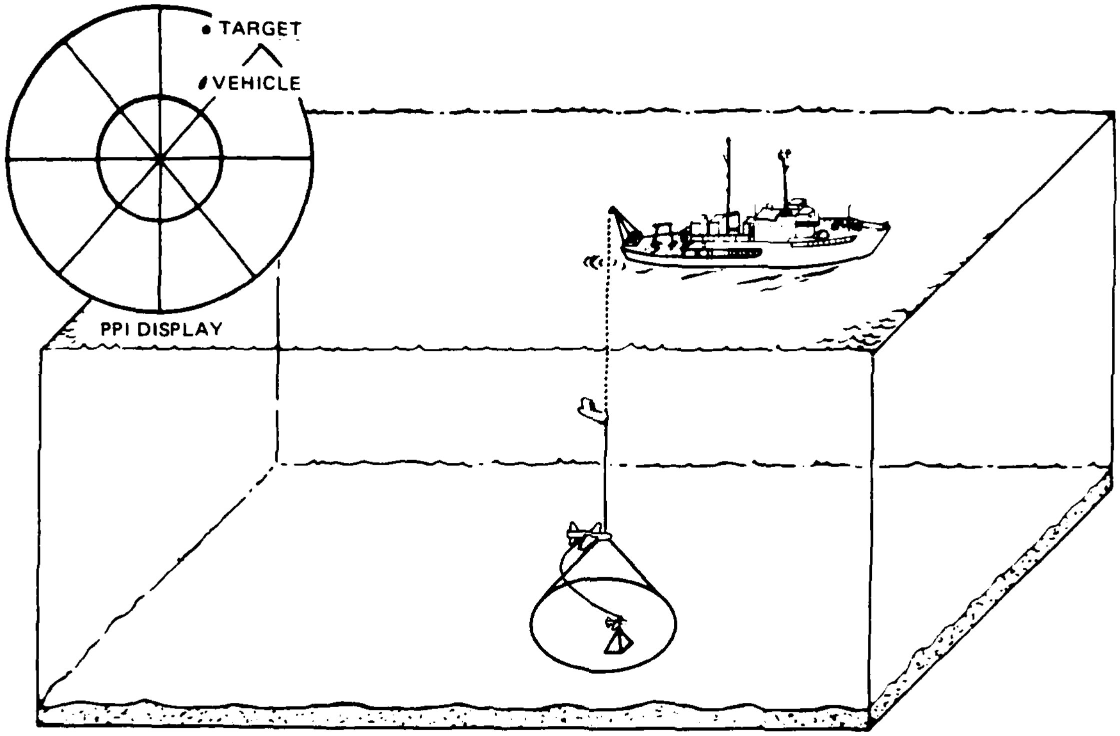

Figure 34. Towed system with trailer video (delayed evaluation phase).

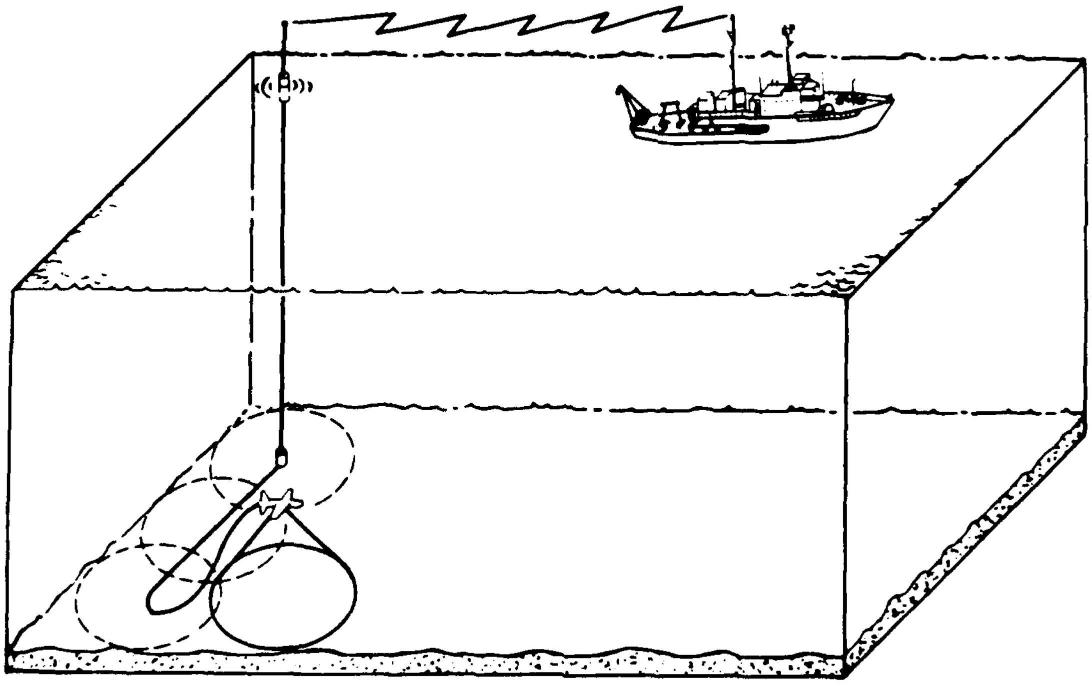

Figure 35. Rf tether link/CURV type search.

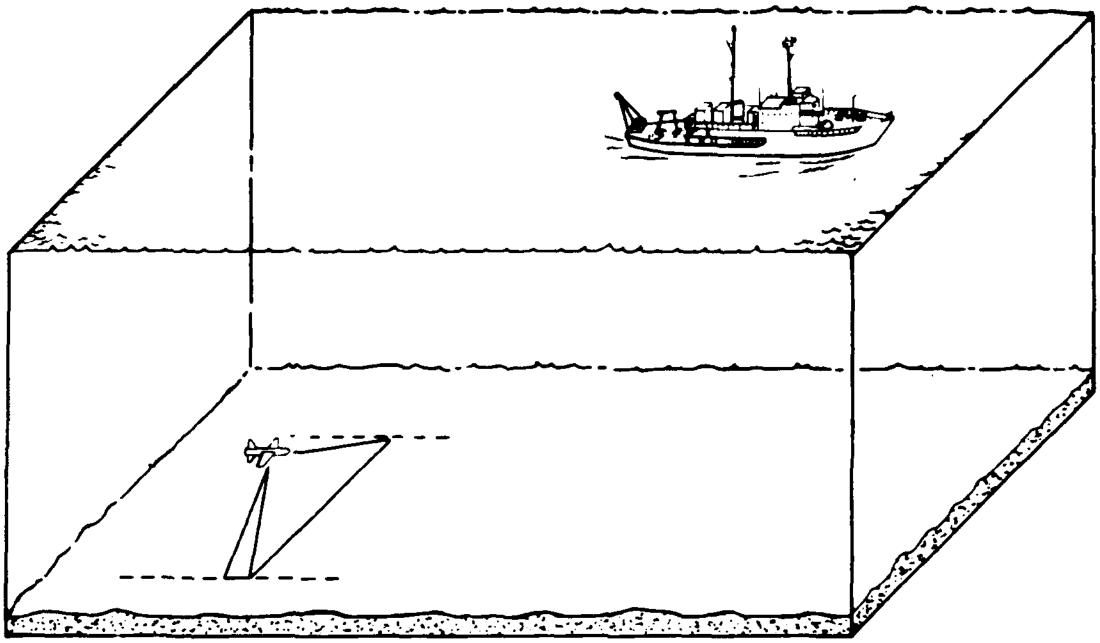

Figure 36. Free-swimmer.

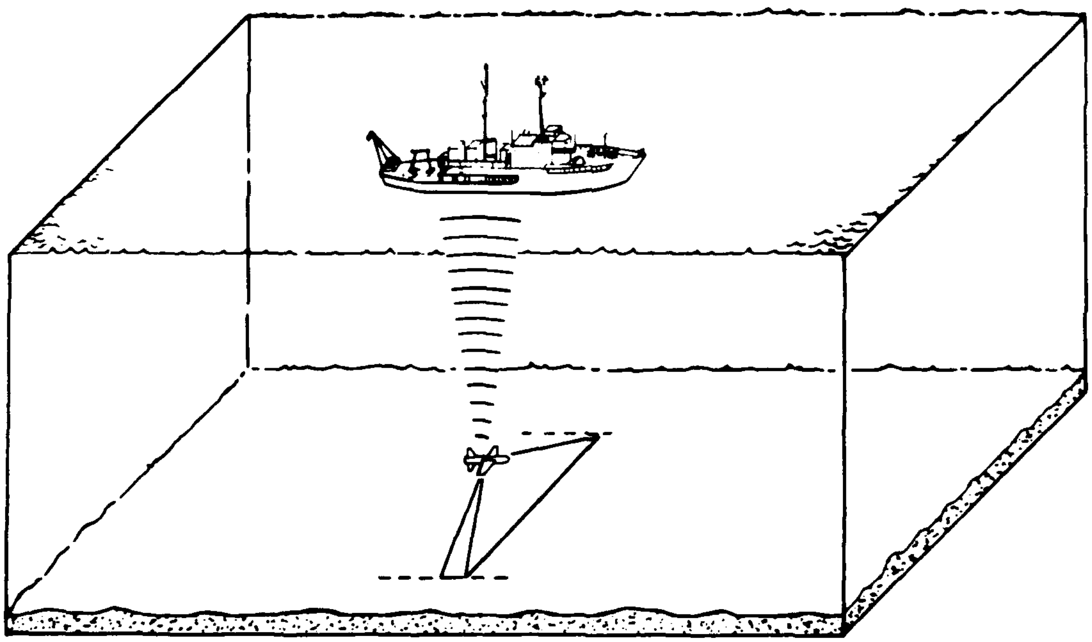

Figure 37. Acoustic link free-swimmer.

still competitive with towed systems. The acoustic link also offers the free-swimmer the options of immediate contact evaluation and a video inspection capability.

ACOUSTIC LINK FREE-SWIMMER/CURV TYPE SEARCH

This system (Figure 38) combines the acoustic link free swimmer concept with the scanning sonar technique used in the rf tether link system. The vehicle sequentially searches a series of circles, each circle defined by the useful range of the scanning sonar. Promising sonar contacts are evaluated immediately. All the advantages of the rf tether link system and the acoustic link free swimmer complement each other to produce what should be the most versatile of the seven candidate systems.

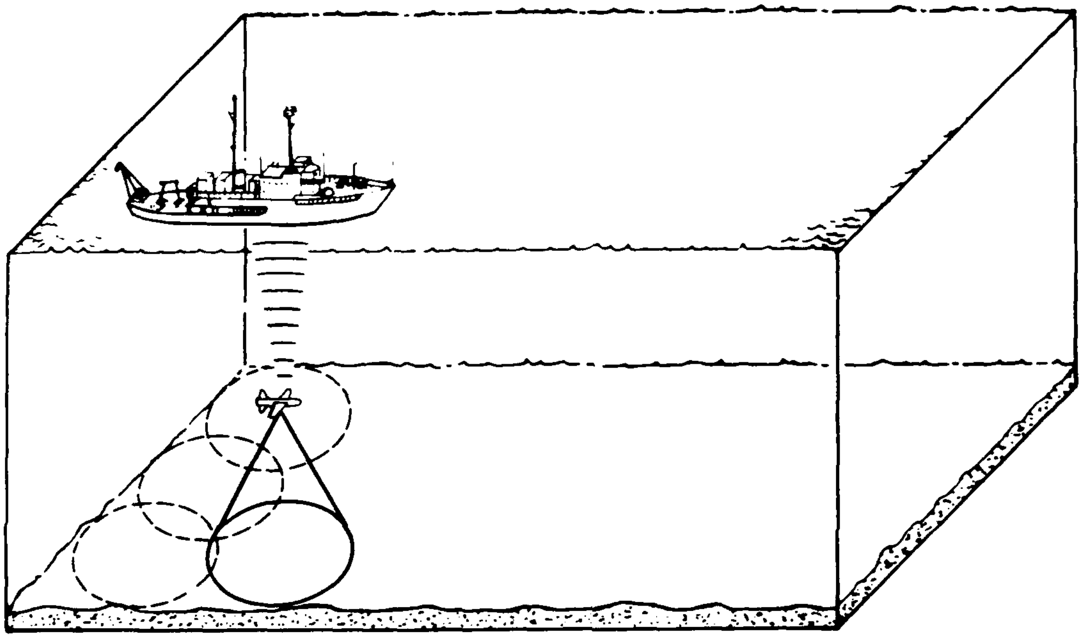

Figure 38. Acoustic link free-swimmer/CURV type search.

SUMMARY

Seven systems have been defined that should be capable of higher search rates than that of the baseline towed system. The following section of this report tabulates the advantages and risks associated with each system, and the section after details the complete performance analysis of these systems.

RISK ANALYSIS

The system characteristics, advantages, and critical technologies for each of the seven candidate systems are listed in Table 6. Although the risks involved in fabricating any of the systems will be associated with the critical technologies, it is again pointed out that all of these technologies or techniques have been previously demonstrated at the component level, and many are "off-the-shelf." None should require extensive development.

Table 6. Candidate systems.

System	System Characterisitcs	Advantages	Critical Technology
Optimized Towed System	Faired cable for higher speeds Computer-aided ship turns for zero turn times	Builds on existing search system technology and techniques Higher speeds, zero turn times	Faired cable with high-speed winch High-speed bottom following Computer-aided ship turns Suitable ship availability
Towed system with decoupling clump	Faired cable for higher speeds Computer-aided ship turns for zero turn times Decoupled sensor vehicle with passive vane control for search, active control for evaluation Scanning sonar on clump	Higher speeds, zero turn times Zero control error Easier computer-aided ship turns Minimal ship towing during evaluation Zero navigation error during final evaluation coverage Video inspection capability Reduced high-speed bottom following risk because of control surfaces in search phase and because not required in evaluation phase	Faired cable with high-speed winch High-speed bottom following (lesser risk than above system) Computer-aided ship turns Suitable ship availability
Towed system with trailer video	Faired cable for higher speeds Computer-aided ship turns for zero turn times Decoupled search sensor vehicle with passive vane control for search, active control for evaluation	Higher speeds, zero turn times Zero control error Easier computer-aided ship turns Minimal ship towing during evaluation Zero navigation error during final evaluation coverage	Faired cable with high-speed winch High-speed bottom following Computer-aided ship turns Suitable ship availability

Table 6. Candidate systems (Continued).

System	System Characterisitcs	Advantages	Critical Technology
	Scanning sonar on clump	Video inspection capability	
	Additional small, laterally mobile video vehicle	Immediate contact evaluation with no time penalities (best case) or reduced contact evaluation time (worst case)	
		Immediate video correlation with sonar (on-scene sonar training)	
Rf buoy with expendable wire link/ CURV-type search	Battery powered vehicle coupled to rf buoy via expendable wire link	No special ship requirements	Expendable wire
		Zero control error	Recovery of two objects (buoy and vehicle)
	Slow scan video	No acoustic interference risk (in CURV-type search, vehicle hovers during sonar operation)	High energy density batteries
	Scanning sonar used in CURV-type search	On-scene sonar adjustment capability	
		No search sensor speed limitation	
		Eliminates need to bottom follow	
		Minimized navigation requirements	
		Immediate contact evaluation with zero navigation error	
Free-swimmer	Battery powered vehicle. All sensor data recorded for playback on deck	No special ship requirements	High energy density batteries
		Zero control error	Total autonomy
			High-speed vertical ascent and descent
			High-speed bottom following
			Possible acoustic interference

Table 6. Candidate systems (Continued).

System	System Characterisitcs	Advantages	Critical Technology
Acoustic link free-swimmer	Battery powered vehicle, acoustic data link	No special ship requirements	High energy density batteries
		Zero control error	Partial autonomy
		Immediate contact evaluation capability	High-speed vertical ascent and descent
		Video inspection capability	High-speed bottom following
			Possible acoustic interference
			Acoustic link
Acoustic link free-swimmer/ CURV-type search	Battery powered vehicle, acoustic data link	No special ship requirements	High energy density batteries
		Zero control error	Partial autonomy
	Scanning sonar used in CURV type search	Video inspection capability	High-speed vertical ascent and descent
		No acoustic interference risk	Acoustic link
		On-scene sonar adjustment capability	
		No search sensor speed limitation	
		Eliminates need to bottom follow	
		Minimized navigation requirements	
		Immediate contact evaluation with zero navigation error	

PERFORMANCE ANALYSIS OF CANDIDATE SYSTEMS

Using the AUSS model, the baseline towed system and the seven candidate systems were subjected to an extensive performance analysis. The basic figure-of-merit was the on-site mission rate, in square nautical miles per hour. Specifically, the expected performance time was determined using the statistical expressions of Appendix C (with complete details given in Appendix D), and this time was divided into the area of the appropriate scenario. The deep and shallow scenarios of Table 1 were used, but the number of targets for each scenario was expanded to four, with target lengths of 10, 30, 100, and 300 feet. (The middle depth scenario of Table 1 was not evaluated because it so closely resembled the deep scenario.) Complete details of all input values and interim results appear in Appendix E.

Tables 7 and 8 present, respectively, the expected performance times and corresponding mission rates for all systems.

Table 7. Expected search times (hrs) for shallow (10 nmi^2) and deep (16 nmi^2) scenarios.

	Shallow				Deep			
Target length, ft.	10	30	100	300	10	30	100	300
Systems:								
Baseline towed system	294.71	120.91	54.69	35.68	296.38	193.51	112.80	66.42
Optimized towed system	81.76	39.38	20.57	12.84	27.66	19.40	16.62	14.28
Towed system with decoupling clump	45.77	20.41	11.71	9.40	19.47	12.50	12.62	13.72
Towed system with trailer video/ immediate evaluation	33.19	11.16	–	–	–	–	–	–
Towed system with trailer video/ delayed evaluation	–	–	9.82	7.45	18.77	12.15	12.26	13.40
Rf tether link/ CURV type search	94.97	25.65	10.08	8.78	27.96	15.17	15.03	8.12
Free-swimmer	54.40	24.94	13.94	10.12	23.39	13.49	10.07	10.00
Acoustic link free-swimmer	117.46	25.82	11.22	9.25	11.64	6.78	5.37	5.29
Acoustic link free-swimmer/CURV type search	59.67	13.23	7.04	5.74	8.19	5.14	5.01	4.31
Median trailer* video rates	33.19	11.16	7.31	5.31	17.52	11.44	11.84	12.67

*See Appendix E.

Table 8. Expected search rates (nmi^2/hr) for shallow and deep scenarios.

	Shallow				Deep			
Target length, ft.	10	30	100	300	10	30	100	300
Systems:								
Baseline towed system	0.0339	0.0827	0.1828	0.2802	0.0540	0.0827	0.1418	0.2409
Optimized towed system	0.1223	0.2539	0.4861	0.7788	0.5785	0.8247	0.9627	1.1204
Towed system with decoupling clump	0.2187	0.4899	0.8540	1.0638	0.8218	1.2800	1.2678	1.1662
Towed system with trailer video/ immediate evaluation	0.3013	0.8961	–	–	–	–	–	–
Towed system with trailer video/ delayed evaluation	–	–	1.0183	1.3423	0.8524	1.3169	1.3050	1.1940
Rf tether link/ CURV type search	0.1053	0.3899	0.9921	1.1389	0.5722	1.0547	1.0645	1.9704
Free-swimmer	0.1838	0.4010	0.7174	0.9881	0.6841	1.1860	1.5889	1.6000
Acoustic link free-swimmer	0.0583	0.3872	0.8913	1.0811	1.3745	2.3599	2.9795	3.0246
Acoustic link free-swimmer/CURV type search	0.1675	0.7559	1.4205	1.7422	1.9536	3.1128	3.1936	3.7123
Median trailer* video rates	0.3013	0.8961	1.368	1.883	0.9152	1.3986	1.3514	1.2628

*See Appendix E.

These tables constitute the primary output of the study and provide sufficient performance data with which the various systems can be fairly compared, assuming that the methods of calculation and the input data of Appendices C through E are taken into account. For ease in interpreting the data, the Table 7 results are plotted in Figures 39 through 44.

Examining the shallow scenario first, one can see in Figure 39 that the best systems are the towed with trailer video and the acoustic link free-swimmer/CURV type search systems. Each is capable of immediate contact evaluation, creating an advantage over the other systems in most situations.

Against a 10-foot target (Figure 41, left half), all the system search rates are bunched closely together, the best system being the towed with trailer video. Against a small target in this scenario, the sonar swath is quite narrow (330 feet), and the trailing video vehicle can readily sweep back and forth across the entire swath to perform immediate contact evaluation. The acoustic link free-swimmer/CURV type search is only the fourth best system for this target size. Because of the short sonar range for this situation, the free-swimmer has to examine an extraordinary number of circular sonar scans (6943) to search the 16 square nautical mile area. The advantage of the free-swimmer's high speeds between

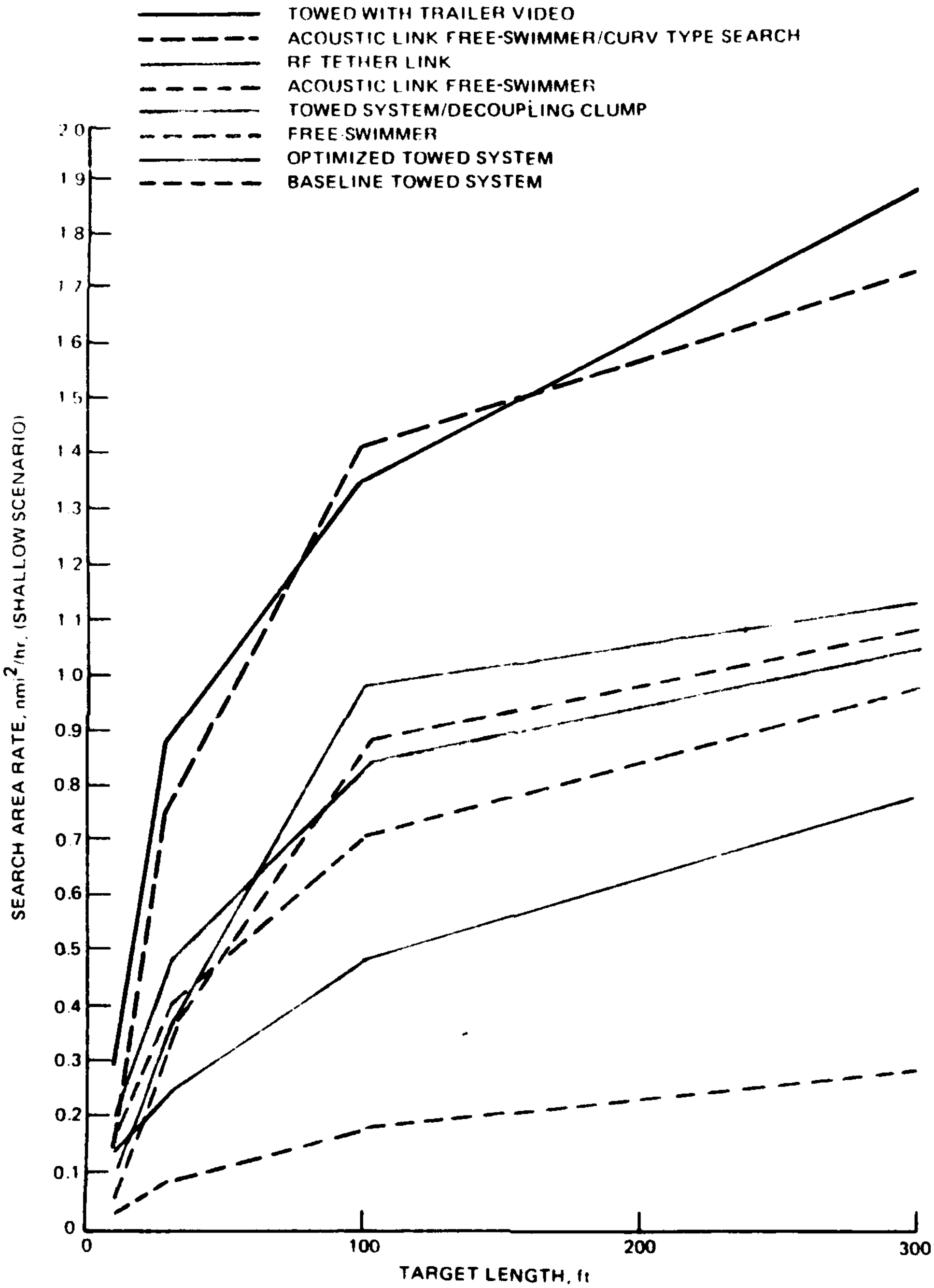

Figure 39. Search area rates versus target length, shallow scenario.

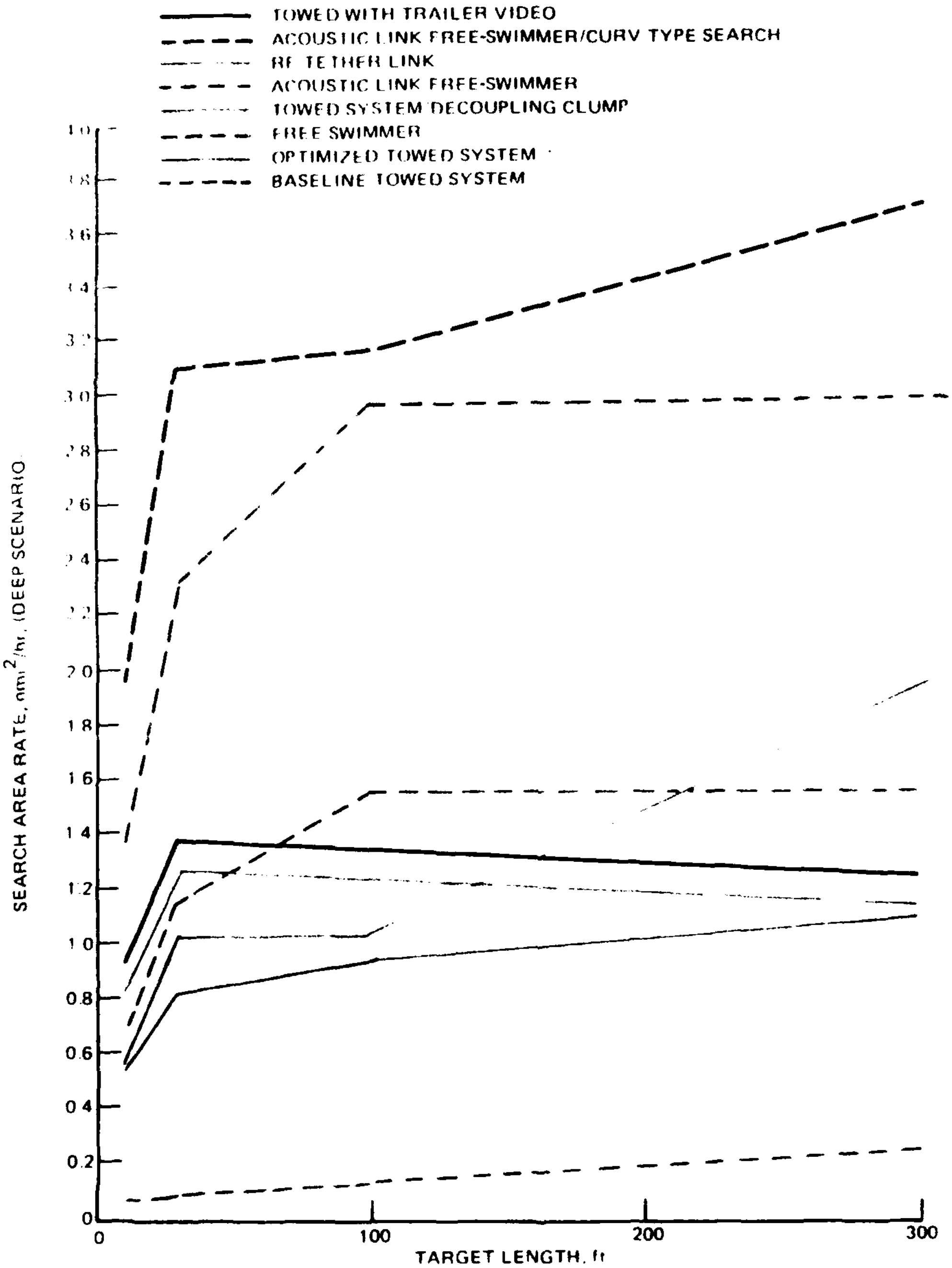

Figure 40. Search area rates versus target length, deep scenario

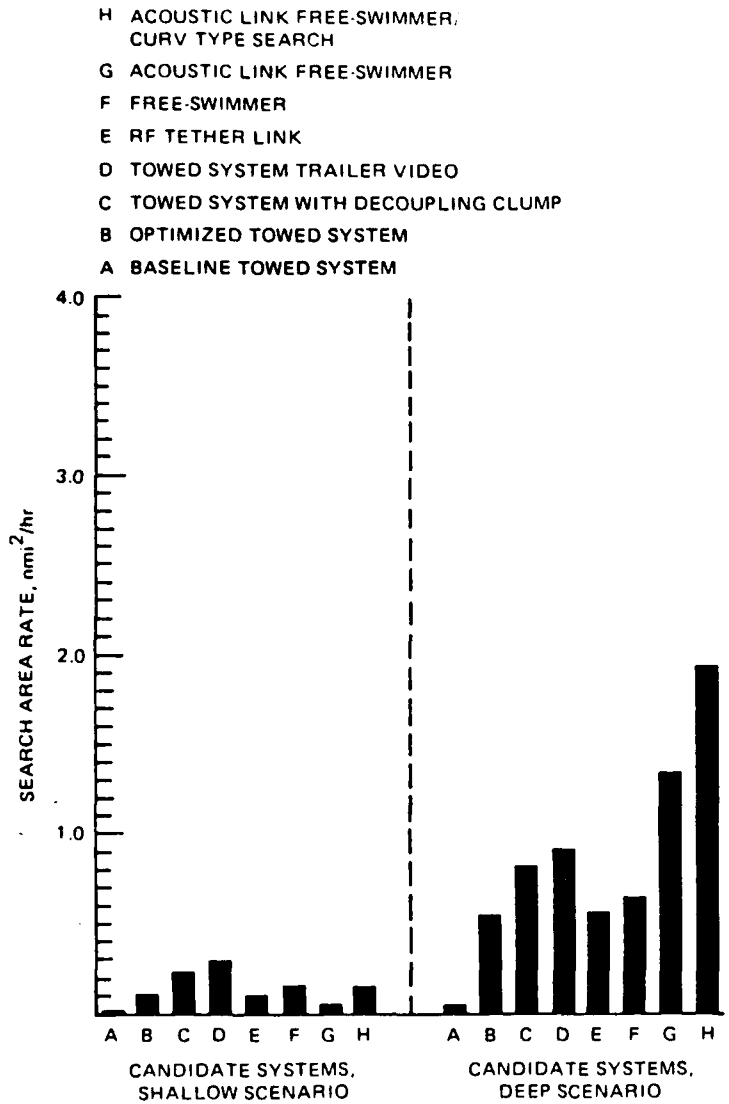

Figure 41. Search area rates against 10-ft target.

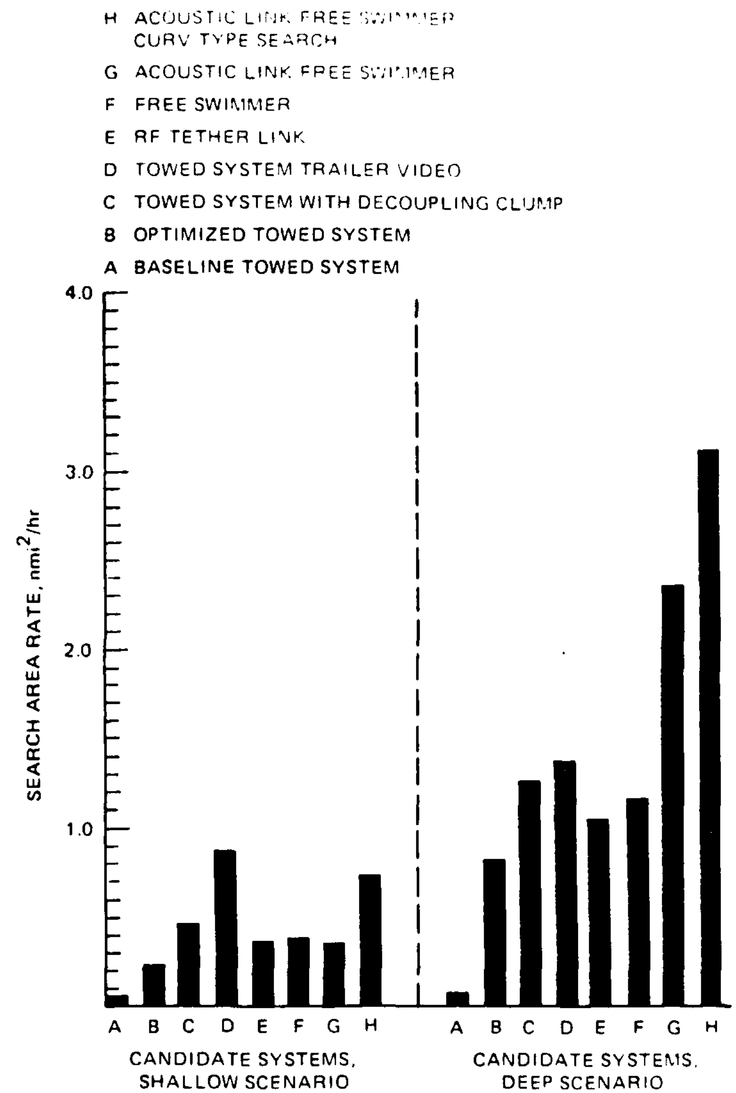

Figure 42. Search area rates against 30-ft target.

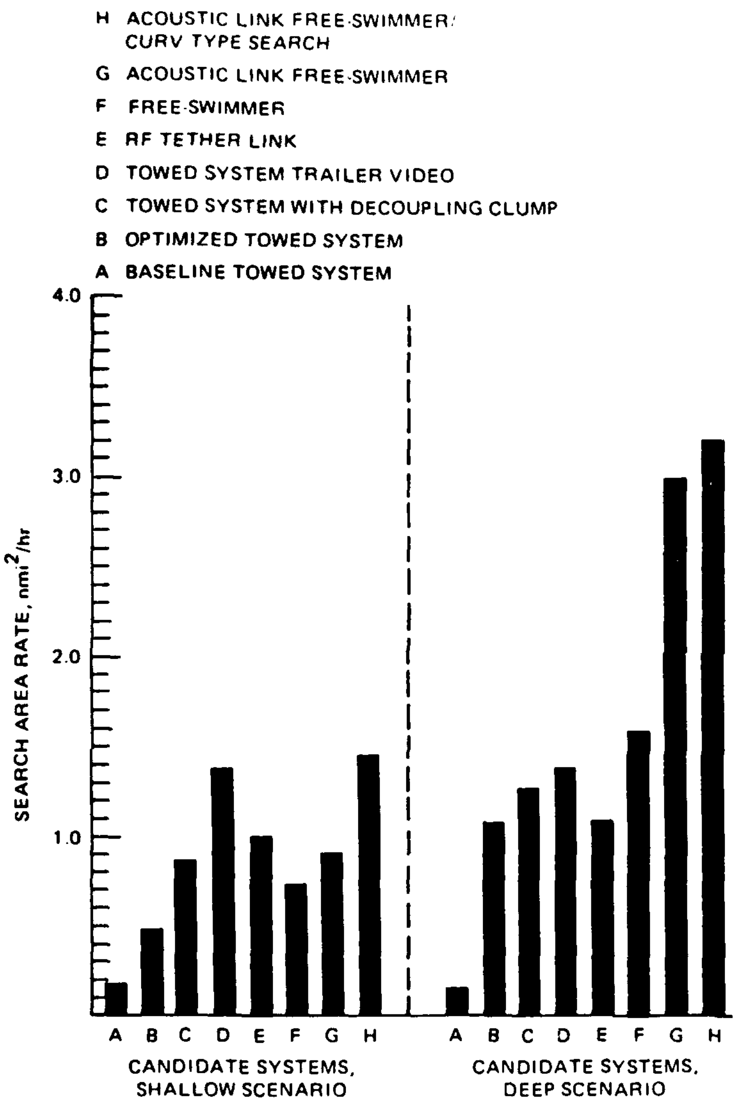

Figure 43. Search area rates against 100-ft target.

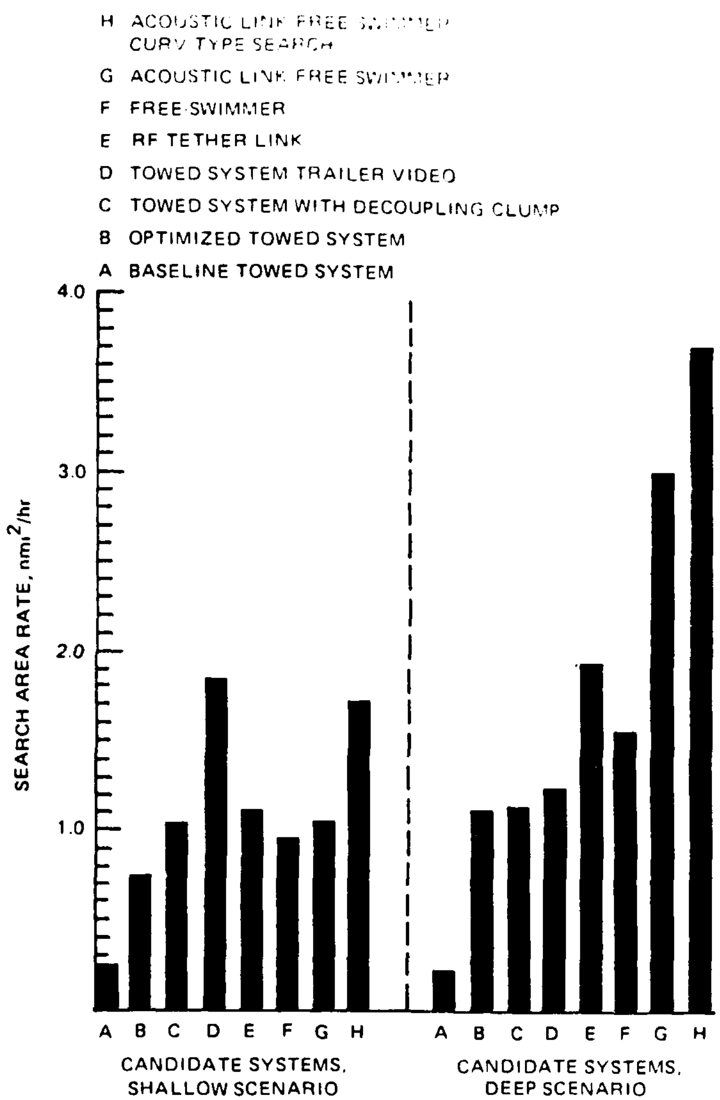

Figure 44. Search area rates against 300-ft target.

scans is therefore negated by the high percentage of time it has to spend hovering and scanning.

Against a 30-foot target (Figure 42, left half), the number of required scans in the CURV search mode is reduced by a factor of nine from the previous case, and the acoustic link free-swimmer/CURV type search system effectively competes with the towed trailer video system as the best system. Both systems in this case display a clear superiority over all other systems.

The same two systems continue to excel for the 100-foot and 300-foot targets (Figures 43 and 44).

Examining the deep scenario results, one can see in Figure 40 that the acoustic link free-swimmer/CURV type search is the superior system for all target lengths, with the standard acoustic link free swimmer (with side looking sonar) as the second best. The superiority of the free swimmers in the deep scenario can be attributed to the higher speeds they can achieve relative to towed system speeds.

Four towed systems were evaluated during the study (the baseline towed system plus the first three elements of Table 6). As expected, each improvement to a given towed system yielded improved search rates, for both scenarios and for all target sizes. Towed system results are separately summarized in Appendix G.

Figures 41 through 44 compare shallow and deep scenario search rates, with the deep scenario rates considerably exceeding those of the shallow. The better results in the deep case are less a function of depth than of the terrain and visibility conditions associated with the deep and shallow cases. The worst case terrain and visibility conditions associated with the shallow scenario result in narrow sonar and video swaths and in sensor-limited search speeds. These limited system capabilities severely reduce shallow scenario performance rates.

Performance gains relative to the baseline towed system rate are presented in Table 9. In general, all proposed systems achieved improved results over the baseline system results. Table 9 indicates how dramatic these gains were for certain cases.

All results above relate to on-site search rates and to intact targets. Extrapolations into the areas of logistics and debris field searches are presented in Appendix F.

CONCLUSIONS

All candidate systems offered significant improvements over the baseline towed system rates. In the shallow case, improvements ranged from 2.7 to 10.8 times the baseline rate. In the deep case, improvements ranged from 4.6 to 37.6 times the baseline rate.

Deep scenario improvements exceeded shallow scenario improvements primarily because it was possible in the deep case to significantly boost vehicle speeds. In the shallow case, speeds were sensor limited.

As expected, each towed system improvement yielded an improved mission rate in both scenarios and for all target sizes. The best towed system, the towed system with the trailing video vehicle, was essentially the best performer of all the systems in the shallow case. In the shallow scenario, sonar swaths were relatively narrow, and the excursions of the small video vehicle readily covered a large percentage of these swaths. It was this ability to perform immediate contact evaluation with no time penalties that produced the superior results.

Table 9. Ratio of advanced system search rates to baseline towed system search rate for shallow and deep scenarios.

	Shallow				Deep			
Target length, ft	10	30	100	300	10	30	100	300
Systems:								
Baseline towed system	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Optimized towed system	3.6	3.1	2.7	2.8	10.7	9.9	6.8	4.6
Towed system with decoupling clump	6.5	5.9	4.7	3.8	15.2	15.4	8.9	4.8
Towed system with trailer video/ immediate evaluation	8.9	10.8	–	–	–	–	–	–
Towed system with trailer video/ delayed evaluation	–	–	5.6	4.8	15.8	15.9	9.2	4.9
Rf tether link/ CURV type search	3.1	4.7	5.4	4.1	10.6	12.7	7.5	8.2
Free-swimmer	5.4	4.8	3.9	3.5	12.7	14.3	11.2	6.6
Acoustic link free-swimmer	1.7	4.7	4.9	3.9	25.5	28.5	21.0	12.6
Acoustic link free-swimmer/CURV type search	4.9	9.2	7.8	6.2	36.2	37.6	22.5	15.4
Median trailer video ratio	8.9	10.8	7.5	6.7	16.9	16.9	9.6	5.2

The best overall performer was the acoustic link free-swimmer in the CURV search mode. Its high speeds between scans and its capacity for immediate contact evaluation made it competitive with the towed/trailer video system in shallow water and made it a clear standout in deep water. This system also offers the best of those features that do not directly affect the mission rate, including minimal navigation requirements and minimal ship interface requirements.

Because of the considerable improvements shown in Figures 39 through 44, the search community should be made aware of the suggested configurations and possible benefits. Test programs should be generated to confirm the feasibility of the acoustically linked vehicle with scanning sonar for broad-area search.

APPENDIX A
AUSS COMPUTER MODEL

PREFACE

This appendix describes the Deep Ocean Floor Search Performance Computer Model developed by NOSC under the Advanced Unmanned Search System (AUSS) Project from 1973 through 1978.*

The measure of required performance, or figure-of-merit, of any search operation is the actual time required to conduct the search. The performance relates directly to operational cost and urgency. The figure-of-merit is calculated by the AUSS model for all types of unmanned deep ocean search (except those involving adaptive search patterns) and is based on user-specified search scenario and hardware subsystems.

The model can be used for administrative and engineering design trade-off studies on all levels – search systems analysis, subsystems analysis, and detailed design analysis. In addition, it can be used as an aid in selecting search system components and deciding optimum search strategy prior to an actual search operation.

The computer model is a large-scale simulation program designed to be user-oriented and interactive using a computer terminal. The program is written in FORTRAN V for NOSC's Univac 1110 computer. Although it uses over 210,000 words of computer storage, run costs are minimal – $8 to $20 per run. The model has been designed for easy use by those unfamiliar with computers. It has the capability to make permanent copies of outputs of the calculated results and plots of comparisons made while using the program, duplicating what appears on the terminal screen.

The AUSS model calculates the performance, or total mission time, at the search site; search preparation, transit to site, and return to home port are not included. The search problem and hardware subsystems which require user definition include the following:

- Search site environment
- Target characteristics
- On-site navigation systems
- Search system type: tow, tether, tow with tether whip, or free-swimmer
- Surface link (cable or free-swimmer)
- Cable design and dynamics
- Acoustic link requirements
- Vehicle subsystems and characteristics
- Sensor suit

Figure A-1 displays the items typically involved in problem definition and typical results. The appendix concludes with the list of questions and answers used to define the baseline towed system, shallow scenario (as it was defined for the Sensitivity Analysis), culminating in a brief summary.

---

*NOSC TR, "Advanced Unmanned Search System (AUSS) Deep Ocean Floor Search Performance Computer Model Executive Summary," by T. J. Keil (in preparation).

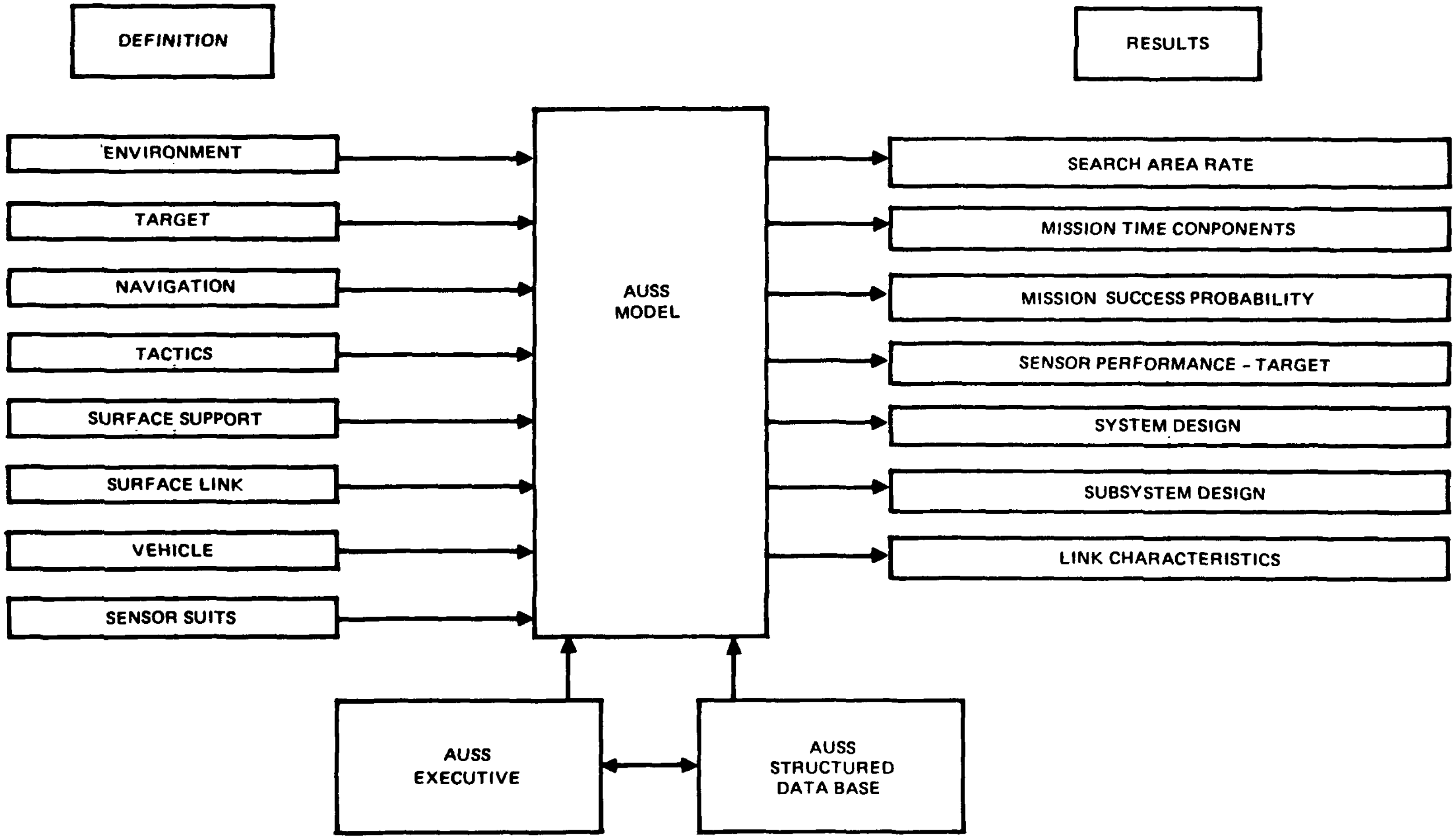

Figure A-1. AUSS search performance model.

SAMPLE QUESTIONS AND RESPONSES REQUIRED TO GENERATE PERFORMANCE CALCULATIONS FOR BASELINE TOWED SYSTEM, SHALLOW SCENARIO

```
*AUSS RUN # 15176.0  (46)              VER: AUSS 65(NOSC)        CA26
INITIAL INPUT                                                    080879

*** ENVIRONMENT ***
SEARCH AREA SIZE(SQ NMI)
>10
AREA SHAPE: (0)SQUARE, (1)RECTANGULAR
>1
SEARCH TRACK LENGTH(N MI):
>5
DEPTH(FT)
>2000
TERRAIN: (1)SMOOTH, (2)ROUGH, (3)SCARP
>3
LOCATION: (1)OPEN OCEAN, (2)COASTAL WATERS
>2
SEA STATE: 0-8
>3

*** TARGET ***
IS TARGET: (1)INTACT, (2)DEBRIS
>1
TARGET SHAPE: (1)SPHERICAL, (2)CYLINDRICAL
>2
TARGET RADIUS(FT):
>1
TARGET LENGTH(FT)
>10

** NAVIGATION **
NAV SYSTEM: (1)SBL, (2)LBL, (3)USERS
>2

*** VEHICLE CONFIGURATION ***
VEHICLE TYPE: (1)TOWED, (2)TETHERED, (3)FREE SWIMMER,
   (4)TOW WITH WHIP
>1
                      *** CABLE VEHICLE INPUT ***

*** VEHICLE SENSOR SUIT ***

** SEARCH PHASE SENSOR SUIT **
  SEARCH SENSORS: (MAX=8)
  AVAILABLE SENSORS: (1)SLS (2)PHOTO (3)MAG (4)TV (5)ROMS (6)ADOSS
                     (7)USERS (8)FLS
GIVE SENSOR NUMBER(S)-SEPARATED BY COMMAS:
>7
MORE? (GIVE SENSOR #'S OR HIT "RETURN")
>
*** USERS SPECIFICATION: SEARCH SENSOR ON TOWED VEHICLE # 1
SENSOR TYPE: (1)VISUAL, (2)NON-VISUAL
>2
OPERATING VELOCITY(KNOTS):
>1.5
OPERATING HEIGHT(FT):
>200
```

```
 TOTAL SWATH WIDTH(FT)
>2000
 TOTAL SWATH GAP WIDTH-HOLIDAY(FT):
>0
 TOTAL SWATH DETECTION PROB(0-1):
>.9
 SENSOR PAYLOAD VOLUME(CU FT)
>1.8
 PAYLOAD WEIGHT(LBS):
>200
 MAXIMUM DEPTH LIMITATION(FT):
>0
 TOTAL POWER REQ'D(KW):
>1.1
 REQUIRED BANDWIDTH(KHZ):
>700
 SENSOR RESOLUTION(FT):
>3
 DEGRADED CHANNEL CAPACITY FACTOR(TYPICAL=3):
>3
 SIGNAL NOISE RATIO(DB)(TYPICAL=30DB):
>30
 FALSE TARGET DENSITY(NUM/SQ NMI):
>.13
 USERS ERROR PROBABILITY(TYP: 1E-3):
>1E-3

 ** EVALUATION PHASE SENSOR SUIT **
   EVALUATION SENSORS: (MAX=1)
   AVAILABLE SENSORS: (2)PHOTO (4)TV (7)USERS
 GIVE SENSOR NUMBER(S)-SEPARATED BY COMMAS:
>7
 SENSOR ADDED TO SENSOR SUIT
   THE MAXIMUM NUMBER OF SENSOR ALLOWED THIS PHASE HAS BEEN SPECIFIED!
 SENSOR SUIT CHGS: TO ADD/DELETE SENSOR USE + OR - SENSOR #
>
 *** USERS SPECIFICATION: EVALUATION SENSOR ON TOWED VEHICLE # 1
 WANT TO USE SEARCH USERS SENSOR? (0)YES, (1)NO
>1
 DATA TRANSMITTED TO SURFACE: (0)NO (1)YES
>1
 OPERATING VELOCITY(KNOTS):
>1.5
 OPERATING HEIGHT(FT):
>30
 TOTAL SWATH WIDTH(FT)
>21.8
 TOTAL SWATH GAP WIDTH-HOLIDAY(FT):
>0
 TOTAL SWATH DETECTION PROB(0-1):
>.999
 MAX BOTTOM TIME(HRS)
>1E7
 PROCESSING TIME(HR/CYCLE):
>0
 SENSOR PAYLOAD VOLUME(CU FT)
>.2
```

```
 PAYLOAD WEIGHT(LBS):
>30
 MAXIMUM DEPTH LIMITATION(FT):
>0
 TOTAL POWER REQ'D(KW):
>1.8
 REQUIRED BANDWIDTH(KHZ):
>600
 SENSOR RESOLUTION(FT):
>.5
 DEGRADED CHANNEL CAPACITY FACTOR(TYPICAL=3):
>3
 NUMBER OF BITS REQ'D(TYPICAL=5):
>5
 FALSE TARGET DENSITY(NUM/SQ NMI):
>.13
 USERS ERROR PROBABILITY(TYP: 1E-3):
>1E-3

 ***PROPULSION SUBSYSTEM SET TO "CANNED" VALUES***

 *** COAXIAL CABLE DESIGN ***
 WANT: (1)AUSS DESIGNED CABLE, (2)USER SPEC CABLE
>2
 ** USER-SPECIFIED CABLE INPUT **

  NO. OF CABLE SEGMENTS (TYPICAL= 50):
>50
  NORMAL DRAG COEFT OF CABLE (TYPICAL= 1.6):
>1.7
  TANGENT DRAG COEFT OF CABLE (TYPICAL= 1E-2):
>.01
  DIAMETER OF CABLE (IN):
>.7
  CABLE WT IN WATER PER FOOT (LBS/FT):
>.5
 GIVE CABLE SEGMENT PRINTOUT FREQUENCY
      1=EVERY SEGMENT, 2=EVERY OTHER SEGMENTED, ETC
>5
 ***FRAME INPUTS SET TO "CANNED" VALUES***


                ********** VEHICLE # 1 - TOWED **********

 *** SEARCH PHASE VEHICLE HEIGHT ***
 WANT: (1)BEST/DESIGN, (4)TO GIVE HEIGHT, (7)LIST OF LIMITS,
      (8)CHANGE SENSOR SUIT
>1
   USERS(NON-VISUAL) LIMITS HEIGHT TO 200 (FT)

 *** SEARCH PHASE VEHICLE SPEED ***
 WANT: (1)BEST/DESIGN, (4)TO GIVE SPEED, (7)LIST OF LIMITS,
      (8)CHANGE SENSOR SUIT
>1
   USERS(NON-VISUAL) LIMITS SPEED TO 1.5 (KNOTS)

 *** EVALUATION PHASE VEHICLE HEIGHT ***
```

```
 WANT: (1)BEST/DESIGN, (4)TO GIVE HEIGHT, (7)LIST OF LIMITS,
      (8)CHANGE SENSOR SUIT
>1
   USERS(VISUAL) LIMITS HEIGHT TO 30 (FT)

 *** EVALUATION PHASE VEHICLE SPEED ***
 WANT: (1)BEST/DESIGN, (4)TO GIVE SPEED, (7)LIST OF LIMITS,
      (8)CHANGE SENSOR SUIT
>1
   USERS(VISUAL) LIMITS SPEED TO 1.5 (KNOTS)

 *** VEHICLE CONTROL ERROR ***
 SEARCH CONTROL ERROR: (0)STANDARD = 600 FT, (1)USERS
>0

 EVALUATION CONTROL ERROR: (0)STANDARD = 600 FT, (1)USERS
>0

              ********** VEHICLE # 1 - TOWED **********

 *** TACTICS ***
 TIME MODE: (1)CLOCK TIME, (2)MEAN TIME
>1
 CONTACT EVALUATION: (1)DELAYED, (2)IMMEDIATE?
>1
 SEARCH PATTERN: (1)PARALLEL PATH, (2)RECTANGULAR SPIRAL
>1
 SEARCH PATTERN COVERAGE: (1)PERIMETER SEARCH, (2)MINIMAL TRACKS
>2
 EVALUATION PATTERN: (1)PARALLEL PATH, (2)RECTANGULAR SPIRAL
>2
 EVALUATION PATTERN COVERAGE: (1)PERIMETER SEARCH, (2)MINIMAL TRACKS
>2
 EVAL TRANSIT SPEED: (1)EVALUATION SPEED, (2)USERS?
>1

 ** VEHICLE WEIGHT/VOLUME CALCS IN PROGRESS **
 ** VEHICLE DESIGN CALCULATIONS IN PROGRESS **
 ** CABLE DESIGN/GEOMETRY CALCS IN PROGRESS **
 ** PERFORMANCE CALCULATIONS IN PROGRESS **
  SEARCH MAX SWATH(FT): 2007, COMB PROB: 0.8983, HEIGHT(FT): 200
    MAX SWATH WITHOUT TARGET AUGMENTATION(FT): 2000

 **SEARCH AREA COVERAGE SPECIFICATION

   WHICH DO YOU WISH TO SPECIFY? (GIVE 2 OF 3):
    (1)TRACK OVERLAP, (2)# OF PASSES, (3)TOTAL PROBABILITY
>1,3
 TRACK OVERLAP: (0)NO OVERLAP, (1)SPECIFY FRACTIONAL OVERLAP,
               (2)SPECIFY ACTUAL OVERLAP
>1
 GIVE TRACK OVERLAP FRACTION(<1):
>.5
 GIVE REQ'D SEARCH AREA TOTAL DETECTION PROBABILITY:
>.9
  EVALUATION MAX SWATH(FT): 31.3, COMB PROB: 0.8792, HEIGHT(FT): 30
    MAX SWATH WITHOUT TARGET AUGMENTATION(FT): 21.8
```

```
**EVALUATION AREA COVERAGE SPECIFICATION

   WHICH DO YOU WISH TO SPECIFY? (GIVE 2 OF 3):
    (1)TRACK OVERLAP, (2)# OF PASSES, (3)TOTAL PROBABILITY
>1,3
 TRACK OVERLAP: (0)NO OVERLAP, (1)SPECIFY FRACTIONAL OVERLAP,
                (2)SPECIFY ACTUAL OVERLAP
>1
 GIVE TRACK OVERLAP FRACTION(<1):
>.5
 GIVE REQ'D EVALUATION AREA TOTAL DETECTION PROBABILITY:
>.9
 WANT A BRIEF SUMMARY: (0)YES, (1)NO
>0
```

```
*AUSS RUN # 15176.0  (46)            VER: AUSS 65(NOSC)          CA26
BRIEF SUMMARY                                                    080879
                            ** ENVIRONMENT **
RECTANGULAR AREA(SQ NMI): 10          DEPTH(FT): 2000
LENGTH: 5 WIDTH: 2                    LOCATION: COASTAL WATERS
SEA STATE: 3 - MODERATE               TERRAIN: SCARP
          ** CYLINDRICAL TARGET (TARGET AUGMENTS SWATH) **
CONDITION: INTACT                     LENGTH(FT): 10 RADIUS(FT) 1
                            ** NAVIGATION **
RELATIVE BOTTOM NAV: LBL              TOTAL RMS NAV ERROR 59.728 FT
       ***** VEHICLE # 1 - TOWED(DESIGN DEPTH: 2000 FT) *****
TOTAL ENCLOSED VOL(CU FT): 21.121  TOTAL DISPLACED VOL(CU FT): 13.655
WEIGHT IN AIR(LB): 1827.9             WEIGHT IN WATER(LBS): 941.2
DESIGN SPEED(KT): 1.5                 TOW CABLE SCOPE(FT): 2143.42
PEAK PROPULSION POWER(KW): 0          PEAK ELECTRONICS POWER(KW): 2.9
PAYLOAD   WT(LB): 230       VOL(CU FT): 2          POWER(KW): 2.9
CONTROL ERROR(FT): SEARCH = 600      EVALUATION = 600
          *** DELAYED EVALUATION TACTICS - CLOCK TIME ***
PHAZ PATRN-COVERAGE TIME LIM  AREA PROB OVERLAP     PASSES  TOT PROB
SEAR PARA-MIN TRACK NO LIMIT  0.9458    50%         *0.9515 0.9
EVAL RECT-MIN TRACK *SENSOR   0.8296    50%         *1.5295 0.9
                            ** SENSOR SUIT **
SENSORS                                  SWATH(FT) DET PROB  HEIGHT(FT)
SEARCH USERS(NON-VISUAL) <TGT>           2000      0.8983    200
  COMBINED AT 1.5 KNOTS                  1802.81   0.8983    200
EVAL USERS(VISUAL) <TGT>                 21.8      0.8792    30
  COMBINED AT 1.5 KNOTS                  27.518    0.8792    30
                       ** PERFORMANCE TIME(HRS) **
PHASE       TRACK    TURNING   TRNST/PC  SURF/DIVE   DECK     TOTAL
SEARCH      43.333   6                   0.3333      2        51.667
EVALUATION  270.29   361.75    2.6848    0.3572      1        636.08
MISSION     313.63   367.75    2.6848    0.6906      3        687.75
PERCENT     45.602   53.471    0.3904    0.1004      0.4362   100
                *** SEARCH AREA RATES(SQ NMI/HR) ***
SEARCH TRACK: 0.2308 SEARCH TOTAL: 0.1935 MISSION: 0.0145

WANT TO: (0)CHANGE DATA, (1)DETAILED SMRY, (2)START OVER, (3)SUMMARY
         (4)CHANGE VEH "DESIGN" MODE, (5)COMPARISON/PLOTS, (6)END RUN
>0
```

```
 CHANGE: (0)NO MORE, (1)ENV, (2)TAR, (3)NAV, (4)VEH SYSTEM
         (5)SINGLE VEHICLE, (6)SENSORS, (7)TACTICS
>6
 SENSOR CHANGE: (0)NO MORE, (1)SUIT, (2)SENSOR TYPE/DATA, (3)VEH HEIGHT
                (4)VEH VELOCITY
>2
 WHICH PHASE: (1)SEARCH (2)EVALUATION (5)ALL PHASES
>1
   SEARCH SENSORS: (7)USERS (MAX=8)
 **** SEARCH USERS SENSOR CHANGES ****
 USERS CHANGE: (0)NO MORE, (1)TYPE, (2)SPEED, (3)HEIGHT
         (4)SWATH, (5)SWATH GAP-HOLIDAY
         (6)DET PROB, (9)VOLUME
         (10)WEIGHT, (11)DIAMETER, (12)POWER REQD, (13)BANDWIDTH
         (14)DEPTH LIMIT, (15)SENSOR RESOLUTION
         (16)DEGRADED CHANNEL CAPACITY FACTOR,
         (17)SIGNAL NOISE RATIO, (18)CENTRAL GAP DET PROB
         (19)# OF BITS REQD, (20)FALSE TAR DENSITY (21)ERROR PROB
>4
 TOTAL SWATH WIDTH(FT)
>330
 TOTAL SWATH GAP WIDTH-HOLIDAY(FT):
>0
 NO CENTRAL GAP SPECIFIED
 USERS CHANGE: (0)NO MORE, (1)TYPE, (2)SPEED, (3)HEIGHT
         (4)SWATH, (5)SWATH GAP-HOLIDAY
         (6)DET PROB, (9)VOLUME
         (10)WEIGHT, (11)DIAMETER, (12)POWER REQD, (13)BANDWIDTH
         (14)DEPTH LIMIT, (15)SENSOR RESOLUTION
         (16)DEGRADED CHANNEL CAPACITY FACTOR,
         (17)SIGNAL NOISE RATIO, (18)CENTRAL GAP DET PROB
         (19)# OF BITS REQD, (20)FALSE TAR DENSITY (21)ERROR PROB
>3
 OPERATING HEIGHT(FT):
>33.7
 USERS CHANGE: (0)NO MORE, (1)TYPE, (2)SPEED, (3)HEIGHT
         (4)SWATH, (5)SWATH GAP-HOLIDAY
         (6)DET PROB, (9)VOLUME
         (10)WEIGHT, (11)DIAMETER, (12)POWER REQD, (13)BANDWIDTH
         (14)DEPTH LIMIT, (15)SENSOR RESOLUTION
         (16)DEGRADED CHANNEL CAPACITY FACTOR,
         (17)SIGNAL NOISE RATIO, (18)CENTRAL GAP DET PROB
         (19)# OF BITS REQD, (20)FALSE TAR DENSITY (21)ERROR PROB
>20
 FALSE TARGET DENSITY(NUM/SQ NMI):
>2.7
 USERS ERROR PROBABILITY(TYP: 1E-3):
>1E-3
 USERS CHANGE: (0)NO MORE, (1)TYPE, (2)SPEED, (3)HEIGHT
         (4)SWATH, (5)SWATH GAP-HOLIDAY
         (6)DET PROB, (9)VOLUME
         (10)WEIGHT, (11)DIAMETER, (12)POWER REQD, (13)BANDWIDTH
         (14)DEPTH LIMIT, (15)SENSOR RESOLUTION
```

```
        (16)DEGRADED CHANNEL CAPACITY FACTOR,
        (17)SIGNAL NOISE RATIO, (18)CENTRAL GAP DET PROB
        (19)# OF BITS REQD, (20)FALSE TAR DENSITY (21)ERROR PROB
>

 VEHICLE CHANGE: (0)NO MORE, (1)TYPE, (2)GEN CHAR, (3)SENSOR SUIT,
    (4)SENSOR CHARACTERISTICS, (5)HEIGHT, (6)VELOCITY,
    (7)CONTROL ERROR
>7
 WHICH PHASE: (1)SEARCH (2)EVALUATION (5)ALL PHASES
>5

 *** VEHICLE CONTROL ERROR ***
 SEARCH CONTROL ERROR: (0)STANDARD = 600 FT, (1)USERS
>1
 SEARCH PHASE - VEHICLE CONTROL ERROR(FT)?
>100

 EVALUATION CONTROL ERROR: (0)STANDARD = 600 FT, (1)USERS
>1
 EVALUATION PHASE - VEHICLE CONTROL ERROR(FT)?
>100

 VEHICLE CHANGE: (0)NO MORE, (1)TYPE, (2)GEN CHAR, (3)SENSOR SUIT,
    (4)SENSOR CHARACTERISTICS, (5)HEIGHT, (6)VELOCITY,
    (7)CONTROL ERROR
>

 CHANGE: (0)NO MORE, (1)ENV, (2)TAR, (3)NAV, (4)VEH SYSTEM
        (5)SINGLE VEHICLE, (6)SENSORS, (7)TACTICS
>7
 TACTICS CHANGE: (0)NO MORE, (1)TIME MODE, (2)AREA COVERAGE,
                 (3)BOTTOM TIME LIMIT, (5)SEARCH PATTERN,
                 (6)TRANSIT SPEED, (7)VEHICLE CONTROL ERROR,
                 (8)EVAL COVERAGE, (9)SEARCH CONTAINMENT PROB,
                 (10)ASCENT/DESCENT, (11)TURN TIME, (12)SUPPORT TIME,
>11
 WHICH PHASE: (1)SEARCH (2)EVALUATION (5)ALL PHASES
>1
 SEARCH TIME/TURN CHANGE: (0)NO MORE, (1)AUSS CALC TIME/TURN,
      (2)USER INPUT
>2
 GIVE TIME PER TURN(HRS):
>1
 SEARCH TIME/TURN CHANGE: (0)NO MORE, (1)AUSS CALC TIME/TURN,
      (2)USER INPUT
>
 TACTICS CHANGE: (0)NO MORE, (1)TIME MODE, (2)AREA COVERAGE,
                 (3)BOTTOM TIME LIMIT, (5)SEARCH PATTERN,
                 (6)TRANSIT SPEED, (7)VEHICLE CONTROL ERROR,
                 (8)EVAL COVERAGE, (9)SEARCH CONTAINMENT PROB,
                 (10)ASCENT/DESCENT, (11)TURN TIME, (12)SUPPORT TIME,
>

 CHANGE: (0)NO MORE, (1)ENV, (2)TAR, (3)NAV, (4)VEH SYSTEM
        (5)SINGLE VEHICLE, (6)SENSORS, (7)TACTICS
>
```

```
ANY MORE CHANGES: (0)YES, (1)NO
>1

                        *** CHECK ***

         ********** VEHICLE # 1 - TOWED **********

** VEHICLE WEIGHT/VOLUME CALCS IN PROGRESS **
** VEHICLE DESIGN CALCULATIONS IN PROGRESS **
** CABLE DESIGN/GEOMETRY CALCS IN PROGRESS **
** PERFORMANCE CALCULATIONS IN PROGRESS **
 SEARCH MAX SWATH(FT): 337, COMB PROB: 0.8896, HEIGHT(FT): 33.7
   MAX SWATH WITHOUT TARGET AUGMENTATION(FT): 330
WANT A BRIEF SUMMARY: (0)YES, (1)NO
>0

*AUSS RUN # 15178.1  (46)             VER: AUSS 65(NOSC)        CA26
BRIEF SUMMARY                                                   080879
                           ** ENVIRONMENT **
RECTANGULAR AREA(SQ NMI): 10        DEPTH(FT): 2000
LENGTH: 5 WIDTH: 2                  LOCATION: COASTAL WATERS
SEA STATE: 3 - MODERATE             TERRAIN: SCARP
        ** CYLINDRICAL TARGET (TARGET AUGMENTS SWATH) **
CONDITION: INTACT                   LENGTH(FT): 10 RADIUS(FT) 1
                           ** NAVIGATION **
RELATIVE BOTTOM NAV: LBL            TOTAL RMS NAV ERROR 59.728 FT
      ***** VEHICLE # 1 - TOWED(DESIGN DEPTH: 2000 FT) *****
TOTAL ENCLOSED VOL(CU FT): 21.121  TOTAL DISPLACED VOL(CU FT): 13.855
WEIGHT IN AIR(LB): 1827.9           WEIGHT IN WATER(LBS): 941.2
DESIGN SPEED(KT): 1.5               TOW CABLE SCOPE(FT): 2143.42
PEAK PROPULSION POWER(KW): 0        PEAK ELECTRONICS POWER(KW): 2.9
PAYLOAD   WT(LB): 230      VOL(CU FT): 2           POWER(KW): 2.9
CONTROL ERROR(FT): SEARCH = 100     EVALUATION = 100
        *** DELAYED EVALUATION TACTICS - CLOCK TIME ***
PHAZ PATRN-COVERAGE TIME LIM  AREA PROB OVERLAP     PASSES  TOT PROB
SEAR PARA-MIN TRACK NO LIMIT  0.9254    50%        *0.9725 0.9
EVAL RECT-MIN TRACK *SENSOR   0.8368    50%        *1.4964 0.9
                           ** SENSOR SUIT **
SENSORS                                SWATH(FT) DET PROB  HEIGHT(FT)
SEARCH USERS(NON-VISUAL) <TGT>         330       0.8896    33.7
  COMBINED AT 1.5 KNOTS                299.81    0.8896    33.7
EVAL USERS(VISUAL) <TGT>               21.8      0.8792    30
  COMBINED AT 1.5 KNOTS                27.518    0.8792    30
                    ** PERFORMANCE TIME(HRS) **
PHASE      TRACK    TURNING   TRNST/PC  SURF/DIVE   DECK     TOTAL
SEARCH     233.33   69                  0.3565      2        304.69
EVALUATION 152.81   927.75    9.372     0.3572      1        1091.29
MISSION    386.14   996.75    9.372     0.7137      3        1395.98
PERCENT    27.661   71.401    0.6714    0.0511      0.2149   100
               *** SEARCH AREA RATES(SQ NMI/HR) ***
SEARCH TRACK: 0.0429 SEARCH TOTAL: 0.0328 MISSION: 7.1634E-3
```

```
WANT TO: (0)CHANGE DATA, (1)DETAILED SMRY, (2)START OVER, (3)SUMMARY
        (4)CHANGE VEH "DESIGN" MODE, (5)COMPARISON/PLOTS, (6)END RUN
>

*AUSS RUN # 15176.2  (46)              VER: AUSS 65(NOSC)        CA26
CHANGES                                                          080879

CHANGE: (C)NO MORE, (1)ENV, (2)TAR, (3)NAV, (4)VEH SYSTEM
        (5)SINGLE VEHICLE, (6)SENSORS, (7)TACTICS
>7
TACTICS CHANGE: (0)NO MORE, (1)TIME MODE, (2)AREA COVERAGE,
                (3)BOTTOM TIME LIMIT, (5)SEARCH PATTERN,
                (6)TRANSIT SPEED, (7)VEHICLE CONTROL ERROR,
                (8)EVAL COVERAGE, (9)SEARCH CONTAINMENT PROB,
                (10)ASCENT/DESCENT, (11)TURN TIME, (12)SUPPORT TIME,
>11
WHICH PHASE: (1)SEARCH (2)EVALUATION (5)ALL PHASES
>2
EVALUATION TIME/TURN CHANGE: (0)NO MORE, (1)AUSS CALC TIME/TURN,
      (2)USER INPUT
>2
GIVE TIME PER TURN(HRS):
>0
EVALUATION TIME/TURN CHANGE: (0)NO MORE, (1)AUSS CALC TIME/TURN,
      (2)USER INPUT
>
TACTICS CHANGE: (0)NO MORE, (1)TIME MODE, (2)AREA COVERAGE,
                (3)BOTTOM TIME LIMIT, (5)SEARCH PATTERN,
                (6)TRANSIT SPEED, (7)VEHICLE CONTROL ERROR,
                (8)EVAL COVERAGE, (9)SEARCH CONTAINMENT PROB,
                (10)ASCENT/DESCENT, (11)TURN TIME, (12)SUPPORT TIME,
>

CHANGE: (C)NO MORE, (1)ENV, (2)TAR, (3)NAV, (4)VEH SYSTEM
        (5)SINGLE VEHICLE, (6)SENSORS, (7)TACTICS
>
ANY MORE CHANGES: (0)YES, (1)NO
>1

                              *** CHECK ***

              ********** VEHICLE # 1 - TOWED **********
** PERFORMANCE CALCULATIONS IN PROGRESS **
WANT A BRIEF SUMMARY: (0)YES, (1)NO
>0
```

```
*AUSS RUN # 15178.2  (46)              VER: AUSS 65(NOSC)        CA26
BRIEF SUMMARY                                                    080879
                        ** ENVIRONMENT **
RECTANGULAR AREA(SQ NMI): 10          DEPTH(FT): 2000
LENGTH: 5 WIDTH: 2                     LOCATION: COASTAL WATERS
SEA STATE: 3 - MODERATE                TERRAIN: SCARP
          ** CYLINDRICAL TARGET (TARGET AUGMENTS SWATH) **
CONDITION: INTACT                      LENGTH(FT): 10 RADIUS(FT) 1
                        ** NAVIGATION **
RELATIVE BOTTOM NAV: LBL               TOTAL RMS NAV ERROR 59.728 FT
       ***** VEHICLE # 1 - TOWED(DESIGN DEPTH: 2000 FT) *****
TOTAL ENCLOSED VOL(CU FT): 21.121  TOTAL DISPLACED VOL(CU FT): 13.855
WEIGHT IN AIR(LB): 1827.9          WEIGHT IN WATER(LBS): 941.2
DESIGN SPEED(KT): 1.5              TOW CABLE SCOPE(FT): 2143.42
PEAK PROPULSION POWER(KW): 0       PEAK ELECTRONICS POWER(KW): 2.9
PAYLOAD   WT(LB): 230       VOL(CU FT): 2          POWER(KW): 2.9
CONTROL ERROR(FT): SEARCH = 100    EVALUATION = 100
          *** DELAYED EVALUATION TACTICS - CLOCK TIME ***
PHAZ PATRN-COVERAGE TIME LIM  AREA PROB OVERLAP     PASSES  TOT PROB
SEAR PARA-MIN TRACK NO LIMIT  0.9254    50%         *0.9725 0.9
EVAL RECT-MIN TRACK *SENSOR   0.8368    50%         *1.4964 0.9
                        ** SENSOR SUIT **
SENSORS                                SWATH(FT) DET PROB  HEIGHT(FT)
SEARCH USERS(NON-VISUAL) <TGT>         330       0.8896    33.7
  COMBINED AT 1.5 KNOTS                299.81    0.8896    33.7
EVAL USERS(VISUAL) <TGT>               21.8      0.8792    30
  COMBINED AT 1.5 KNOTS                27.518    0.8792    30
                   ** PERFORMANCE TIME(HRS) **
PHASE       TRACK    TURNING   TRNST/PC  SURF/DIVE   DECK     TOTAL
SEARCH      233.33   69                  0.3565      2        304.69
EVALUATION  152.81   0         9.372     0.3572      1        163.54
MISSION     386.14   69        9.372     0.7137      3        468.23
PERCENT     82.469   14.736    2.0016    0.1524      0.6407   100
              *** SEARCH AREA RATES(SQ NMI/HR) ***
SEARCH TRACK: 0.0429 SEARCH TOTAL: 0.0328 MISSION: 0.0214

WANT TO: (0)CHANGE DATA, (1)DETAILED SMRY, (2)START OVER, (3)SUMMARY
         (4)CHANGE VEH "DESIGN" MODE, (5)COMPARISON/PLOTS, (6)END RUN
>6
RUNSTREAM ANALYSIS TERMINATED
```

APPENDIX B
SENSITIVITY ANALYSIS RESULTS

This appendix contains the performance curves (search rate versus system parameter) for the systems, scenarios, and system variables evaluated during the Sensitivity Analysis. The curves are categorized as a function of system and scenario. A given curve is most easily found by consulting the list of figures.

LIST OF FIGURES FOR APPENDIX B

LIST OF FIGURES FOR APPENDIX B (Continued)

LIST OF FIGURES FOR APPENDIX B (Continued)

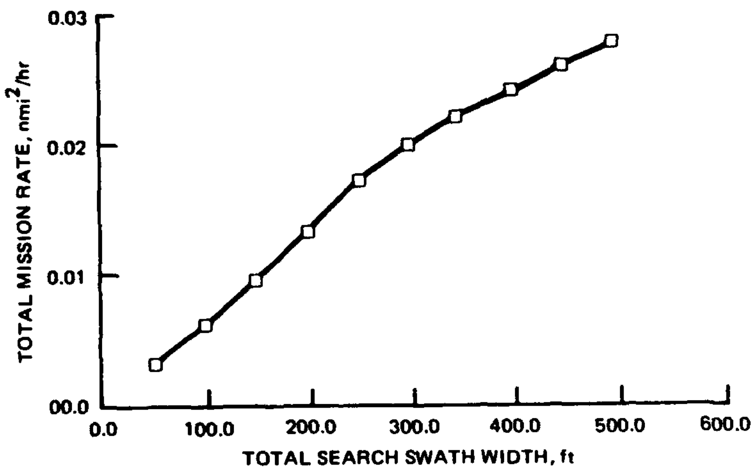

Figure B-1. Total search swath width sensitivity.

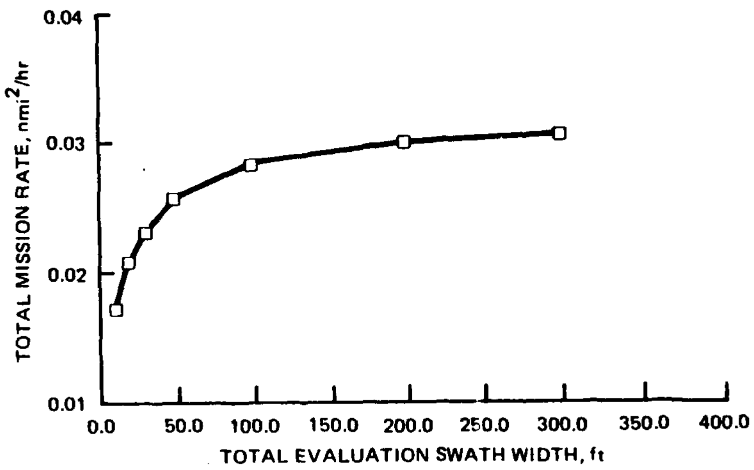

Figure B-2. Total evaluation swath width sensitivity.

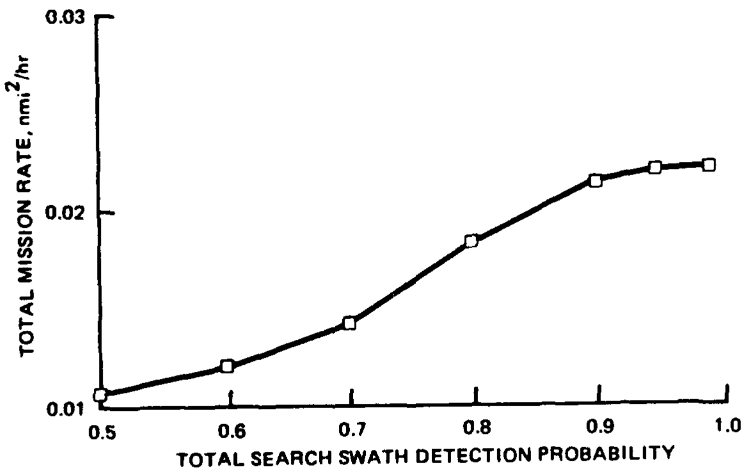

Figure B-3. Total search swath detection probability sensitivity.

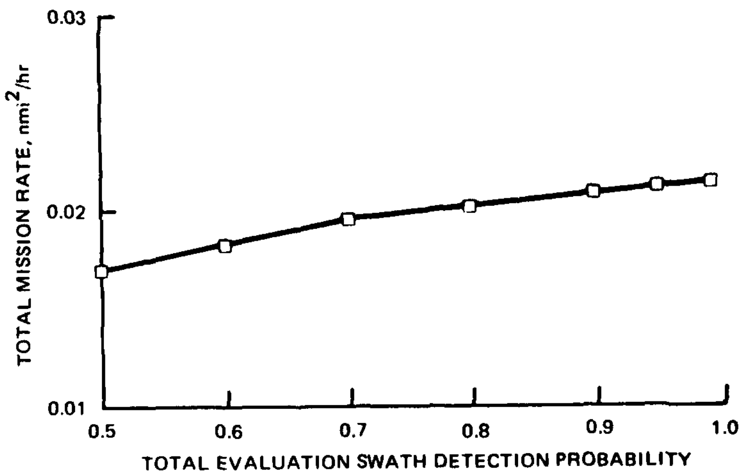

Figure B-4. Total evaluation swath detection probability sensitivity.

Figures B-1 – B-4. Baseline Towed System Shallow Scenario.

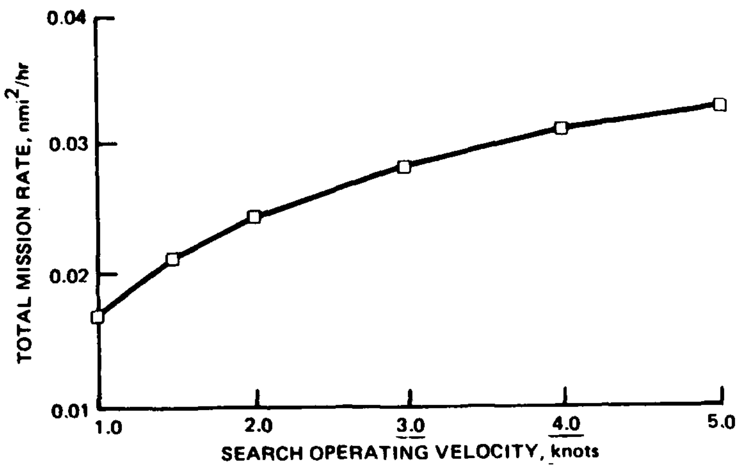

Figure B-5. Search operating velocity sensitivity.

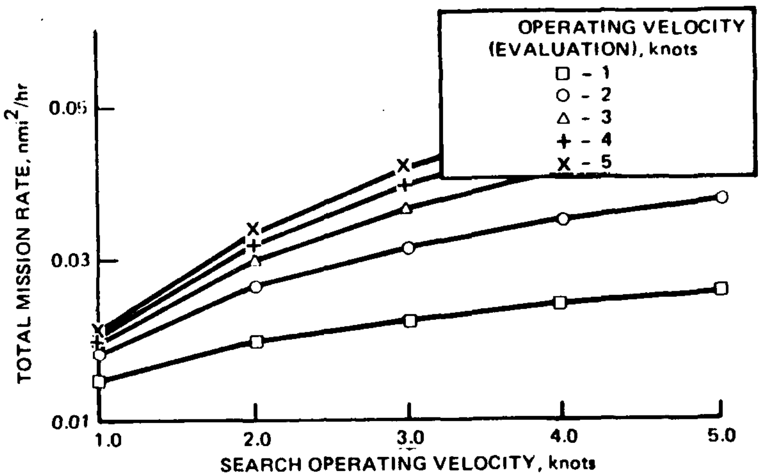

Figure B-6. Search operating velocity/parameters sensitivity.

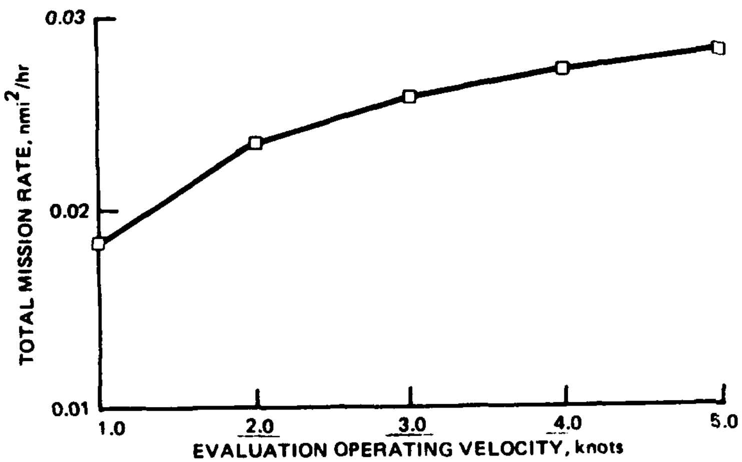

Figure B-7. Evaluation operating velocity sensitivity.

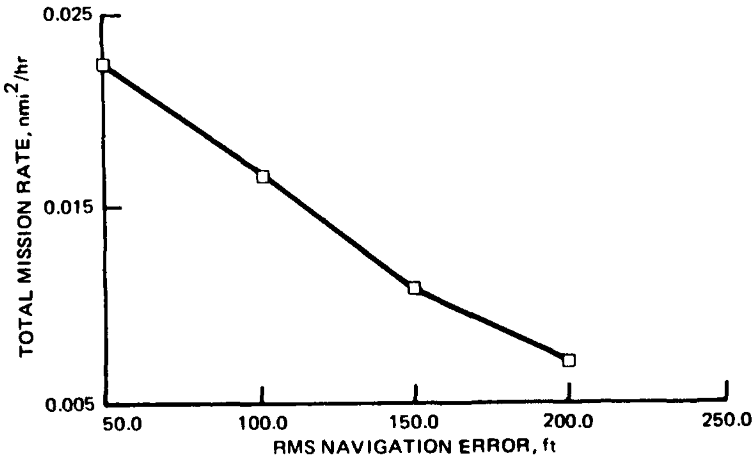

Figure B-8. Rms navigation error sensitivity.

Figures B-5 – B-8. Baseline Towed System Shallow Scenario.

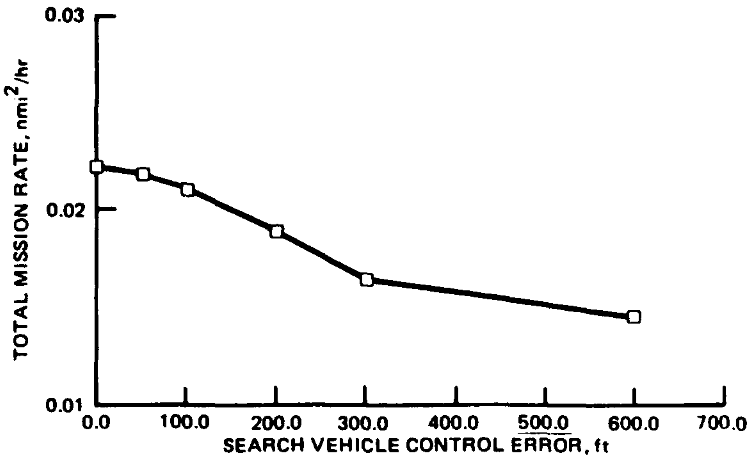

Figure B-9. Search vehicle control error sensitivity.

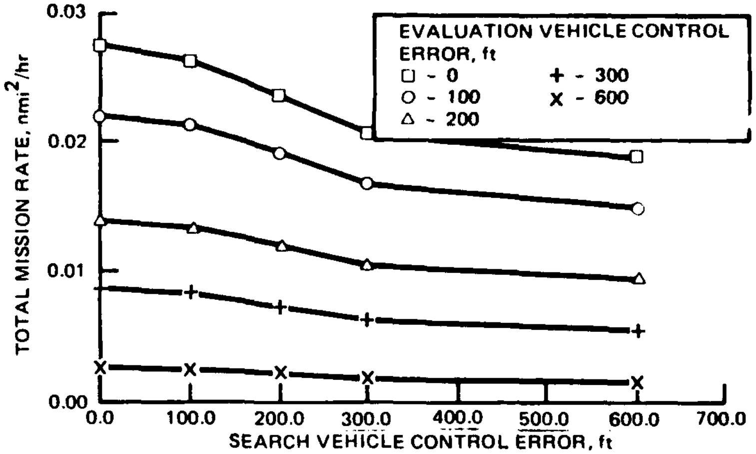

Figure B-10. Search vehicle control error/parameters sensitivity.

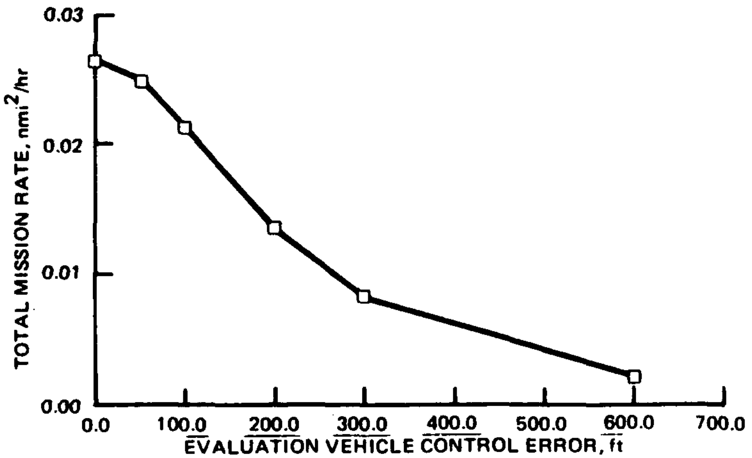

Figure B-11. Evaluation vehicle control error sensitivity.

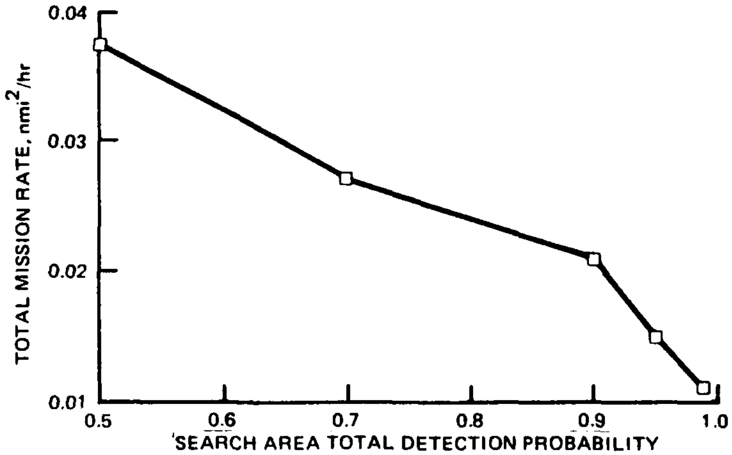

Figure B-12. Search area total detection probability sensitivity.

Figures B-9–B-12. Baseline Towed System Shallow Scenario.

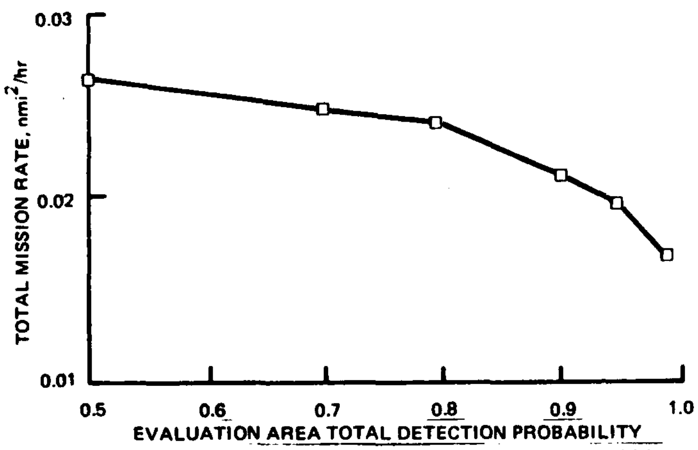

Figure B-13. Evaluation area total detection probability sensitivity.

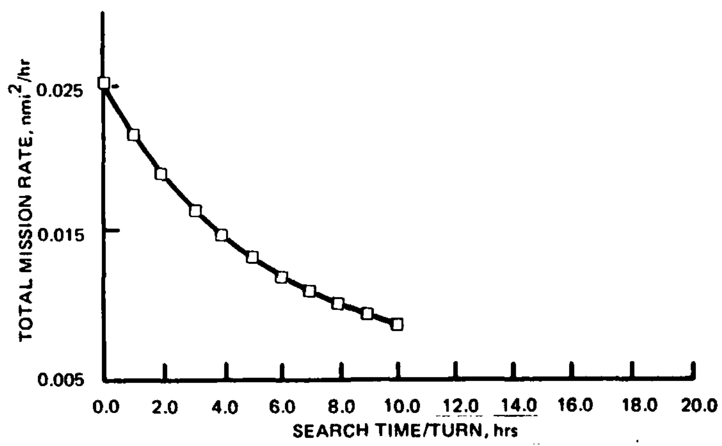

Figure B-14. Search time/turn sensitivity.

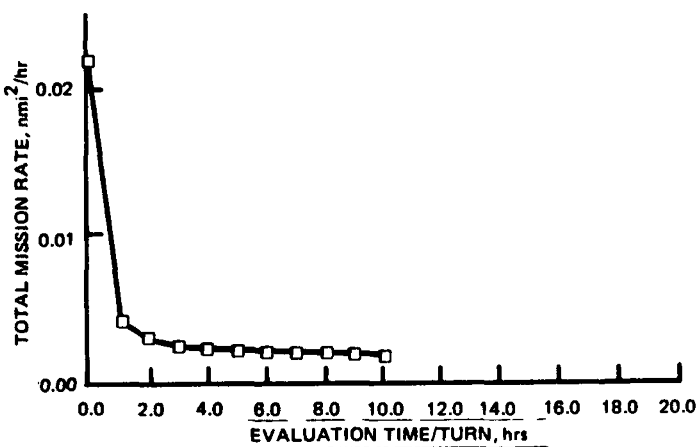

Figure B-15. Evaluation time/turn sensitivity.

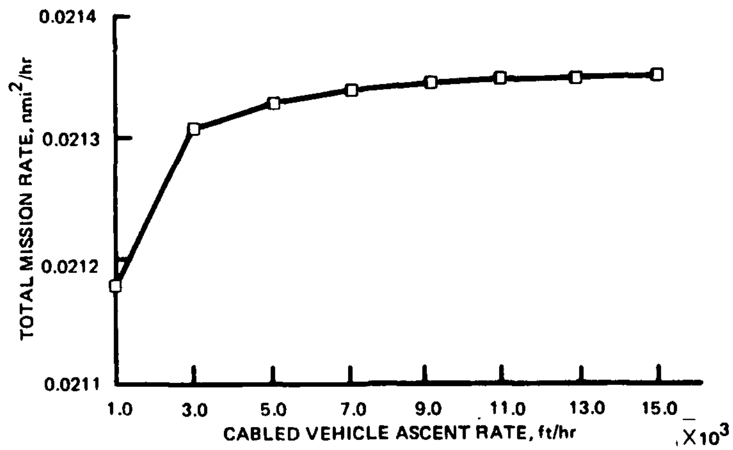

Figure B-16. Cabled vehicle ascent rate sensitivity.

Figures B-13–B-16. Baseline Towed System Shallow Scenario.

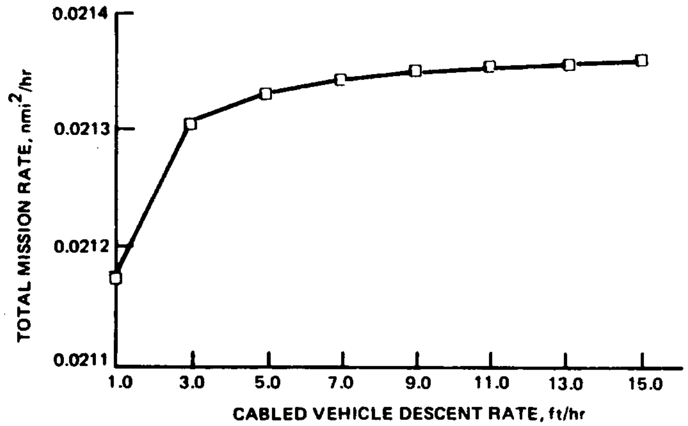

Figure B-17. Cabled vehicle descent rate sensitivity.

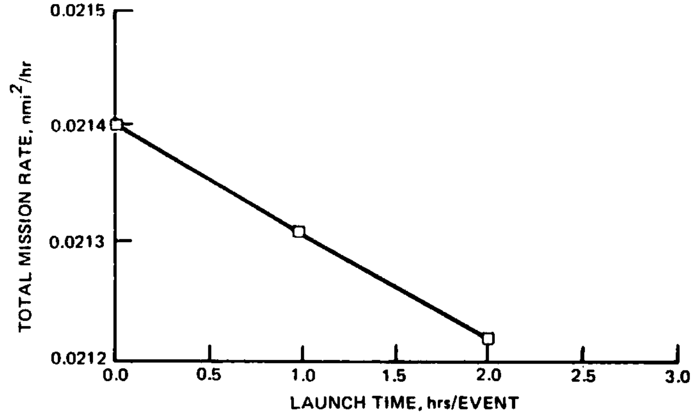

Figure B-18. Launch time sensitivity.

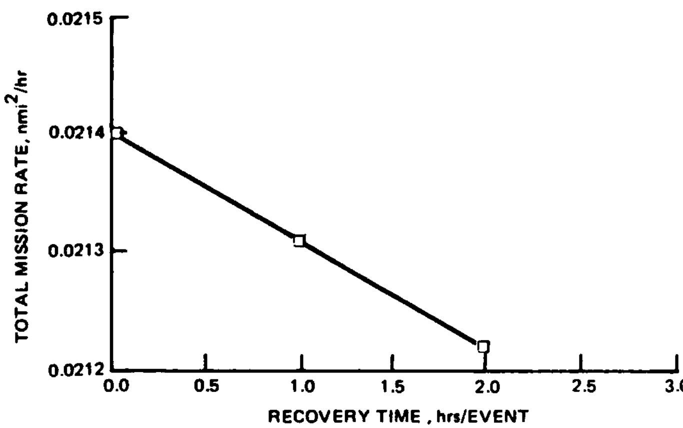

Figure B-19. Recovery time sensitivity.

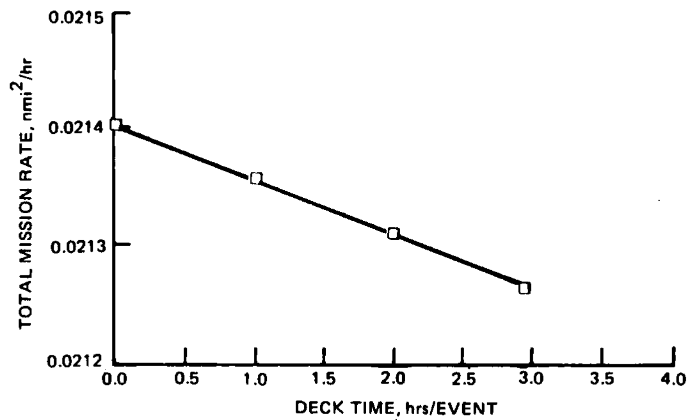

Figure B-20. Deck time sensitivity.

Figures B-17–B-20. Baseline Towed System Shallow Scenario.

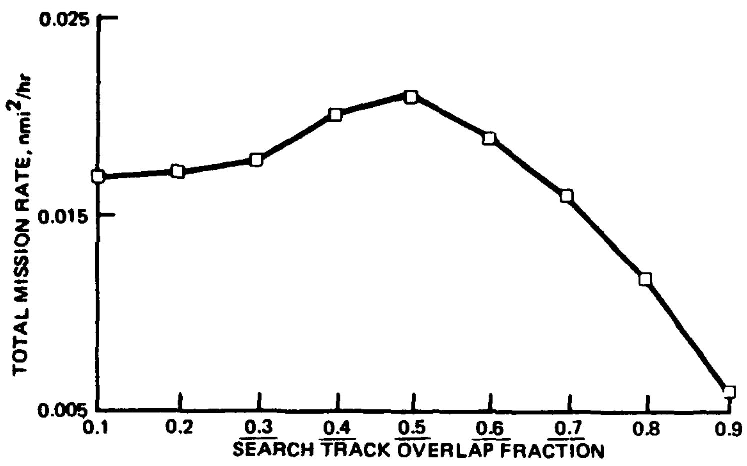

Figure B-21. Search track overlap fraction sensitivity.

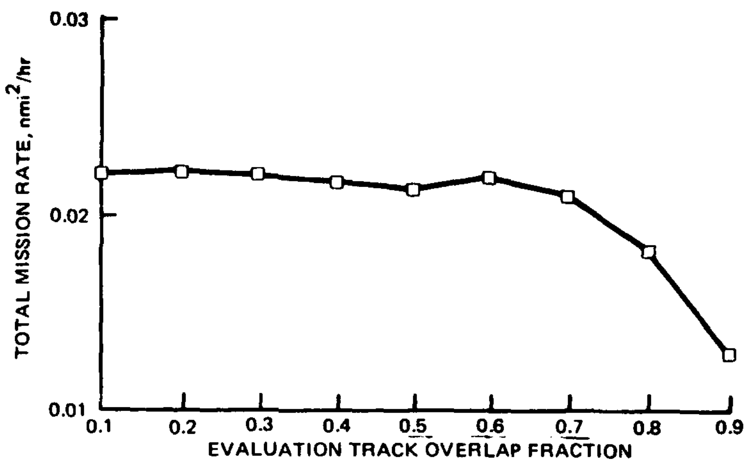

Figure B-22. Evaluation track overlap fraction sensitivity.

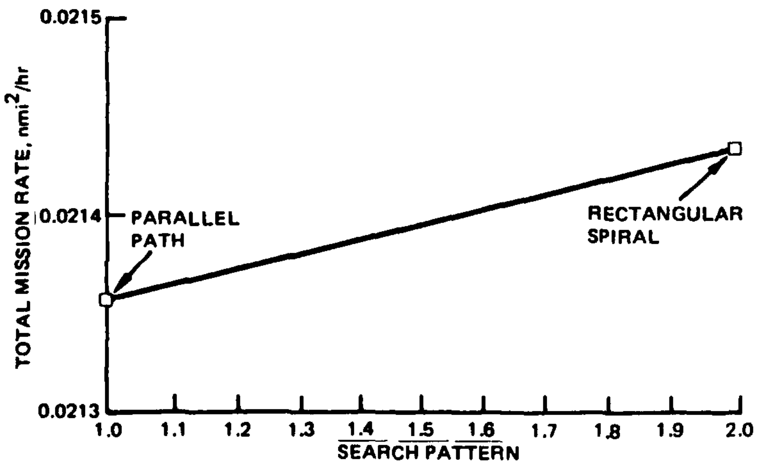

Figure B-23. Search pattern sensitivity.

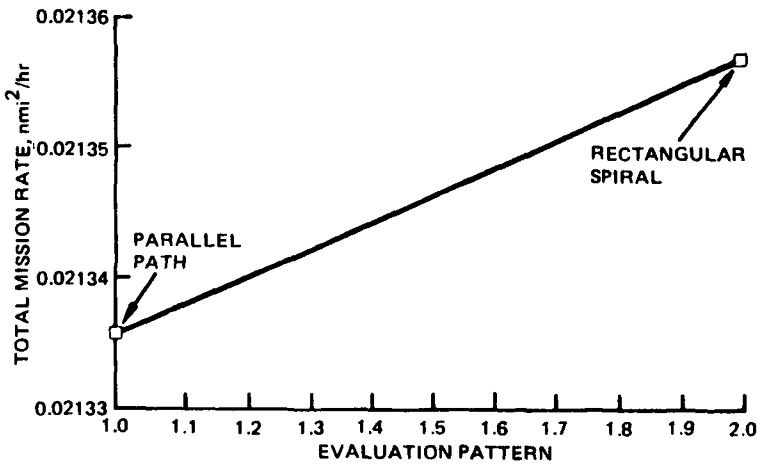

Figure B-24. Evaluation pattern sensitivity.

Figures B-21 – B-24. Baseline Towed System Shallow Scenario.

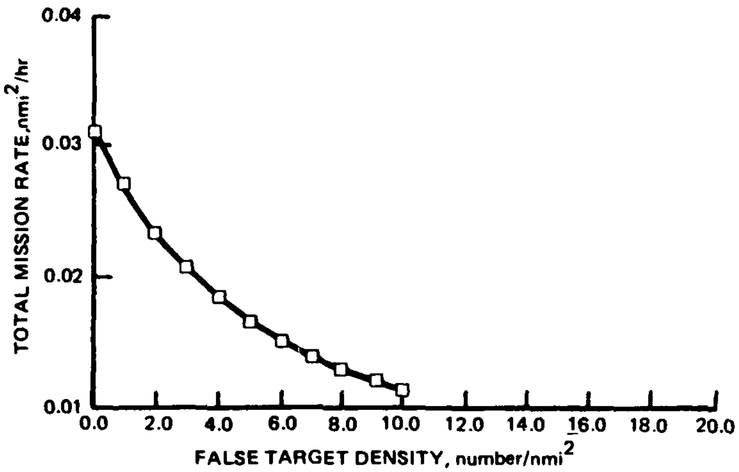

Figure B-25. False target density sensitivity.

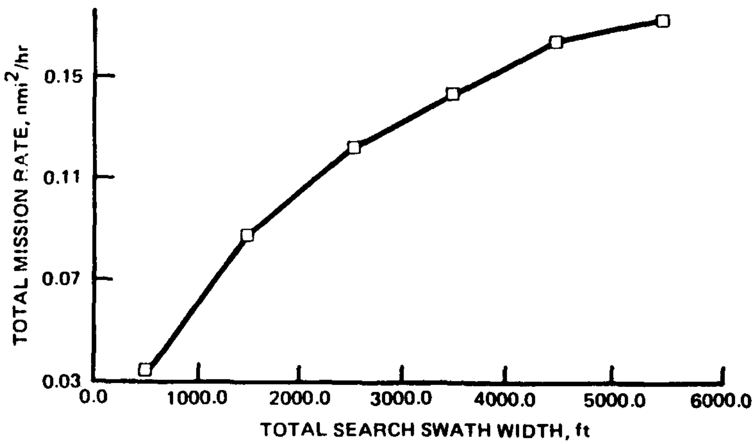

Figure B-26. Total search swath width sensitivity.

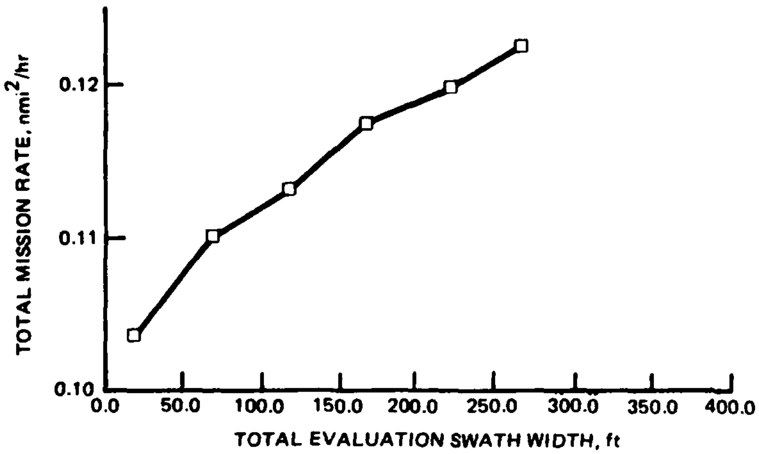

Figure B-27. Total Evaluation swath width sensitivity.

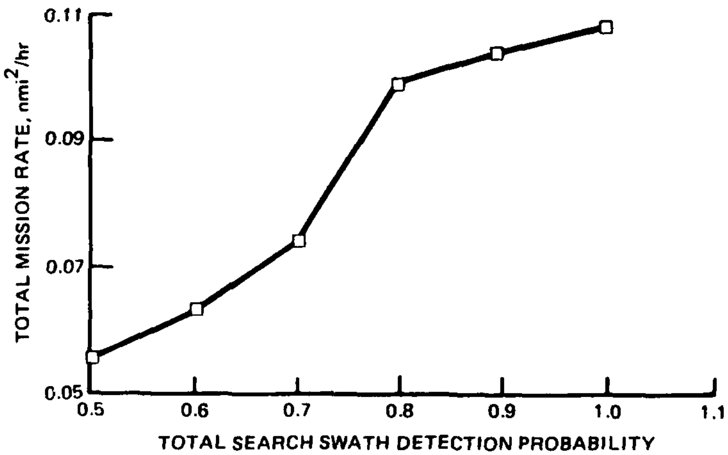

Figure B-28. Total search swath detection probability sensitivity.

Figure B-25. Baseline Towed System Shallow Scenario.
Figures B-26–B-28. Baseline Towed System Middle Scenario.

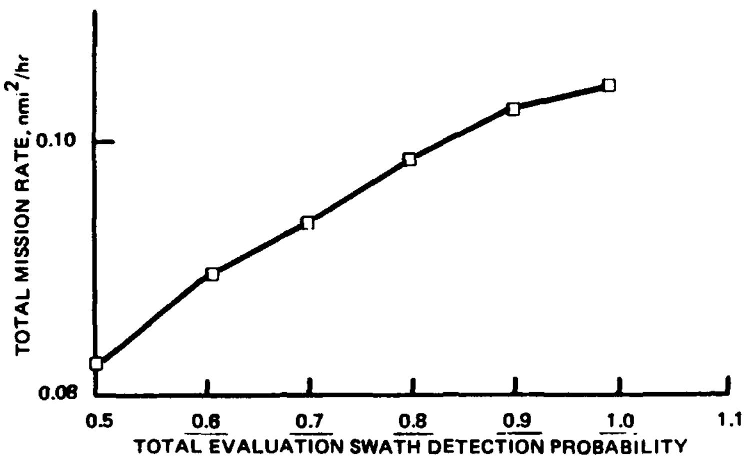

Figure B-29. Total evaluation swath detection probability sensitivity.

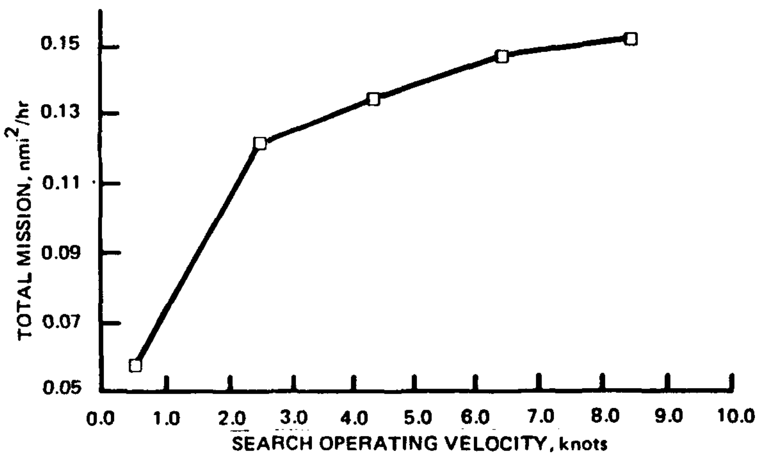

Figure B-30. Search operating velocity sensitivity.

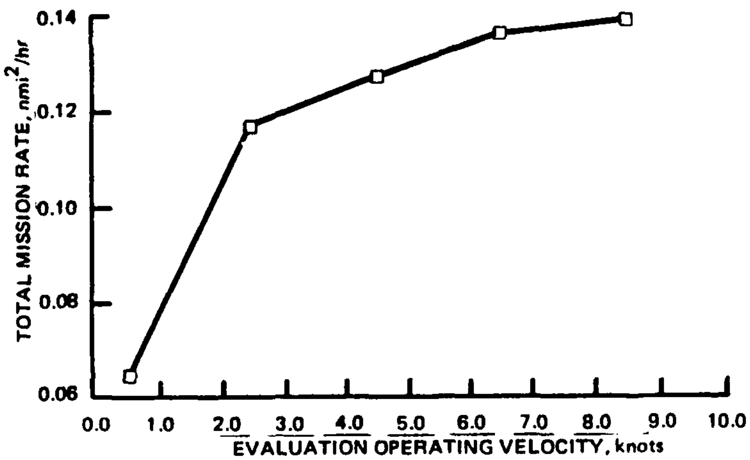

Figure B-31. Evaluation operating velocity sensitivity.

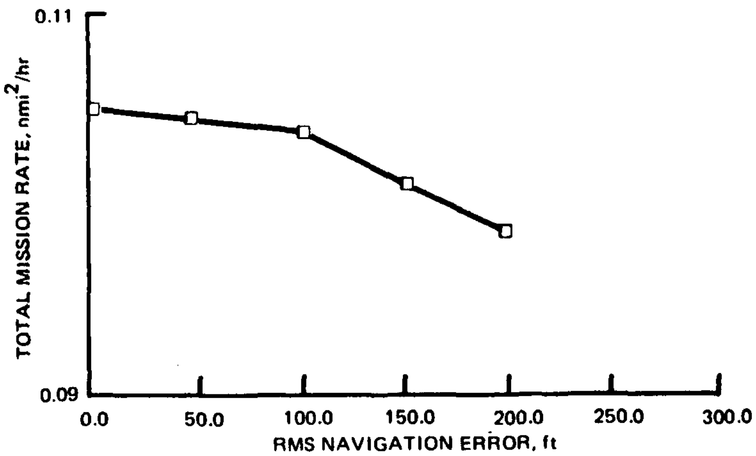

Figure B-32. Rms navigation error sensitivity.

Figures B-29–B-32. Baseline Towed System Middle Scenario.

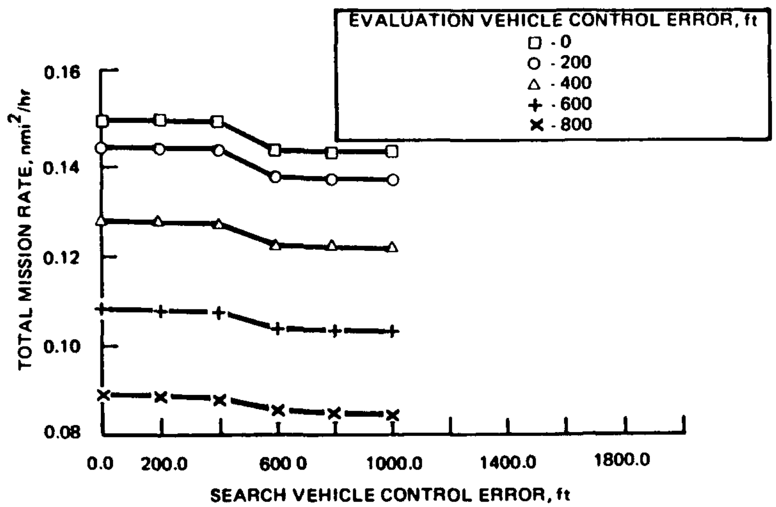

Figure B-33. Search vehicle control error/parameters sensitivity.

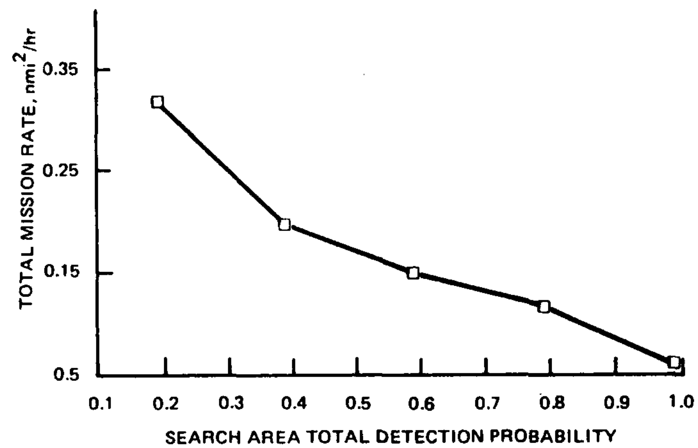

Figure B-34. Search area total detection probability sensitivity.

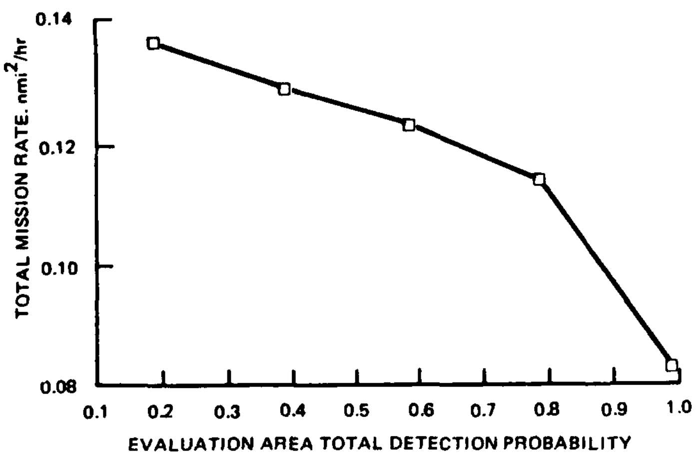

Figure B-35. Evaluation area total detection probability sensitivity.

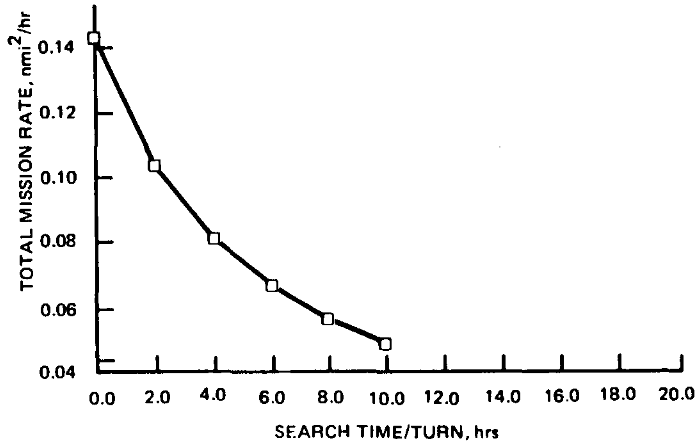

Figure B-36. Search time/turn sensitivity.

Figures B-33 – B-36. Baseline Towed System Middle Scenario.

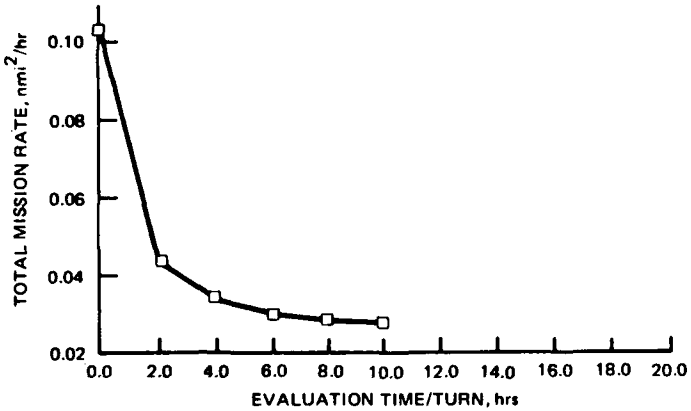

Figure B-37. Evaluation time/turn sensitivity.

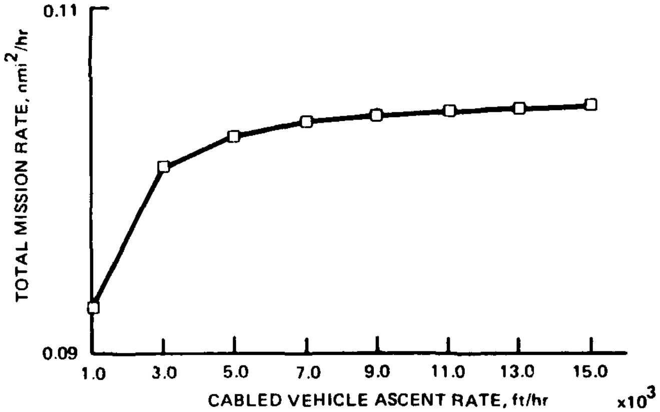

Figure B-38. Cabled vehicle ascent rate sensitivity.

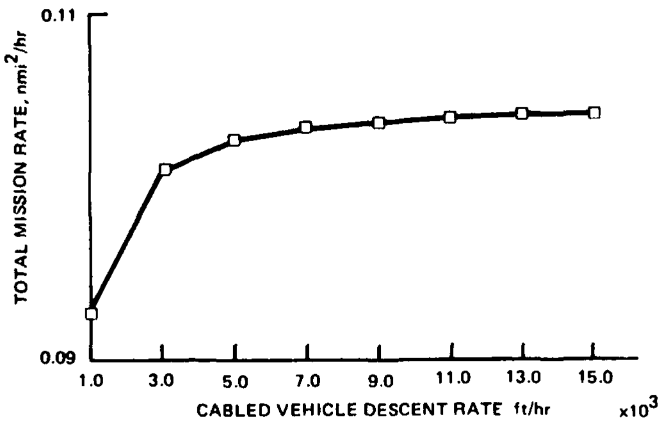

Figure B-39. Cabled vehicle descent rate sensitivity.

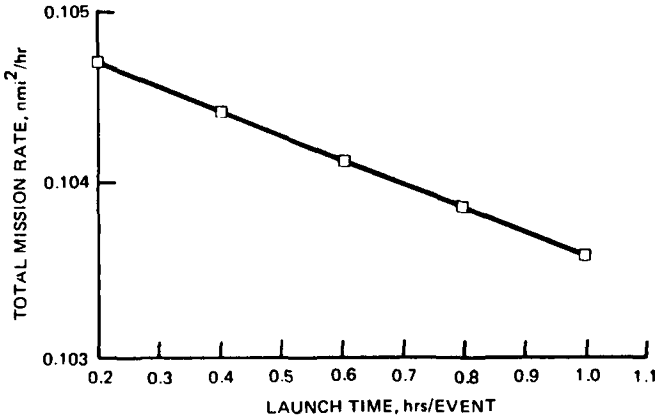

Figure. B-40. Launch time sensitivity.

Figures B-37 – B-40. Baseline Towed System Middle Scenario.

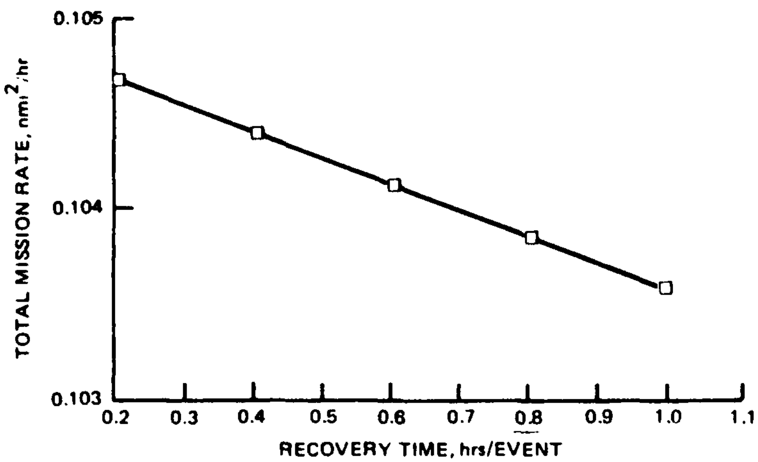

Figure B-41. Recovery time sensitivity.

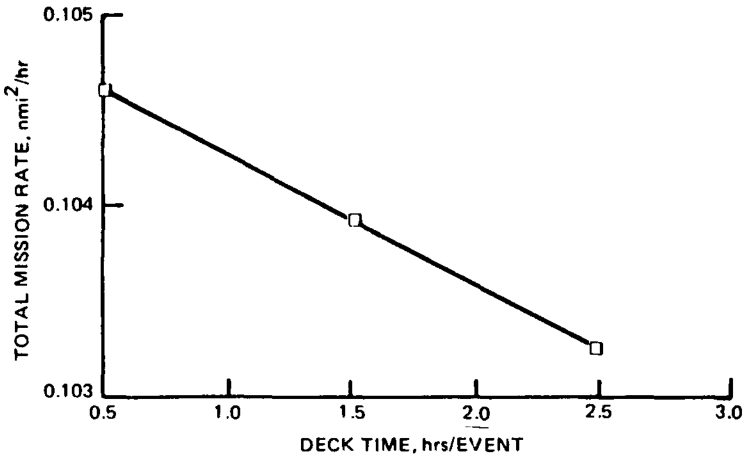

Figure B-42. Deck time sensitivity.

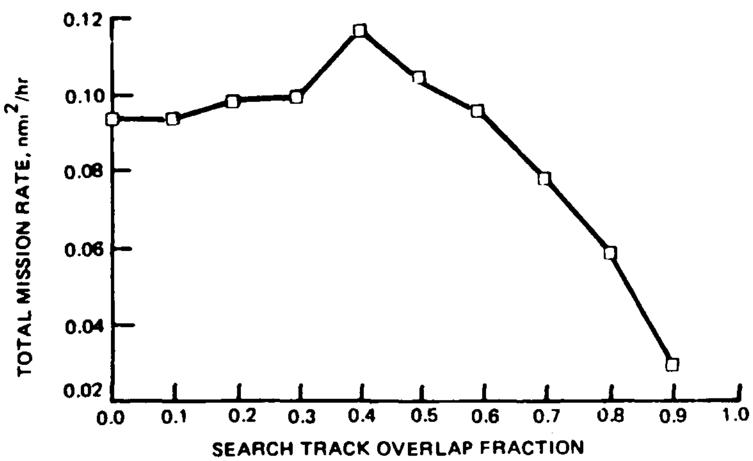

Figure B-43. Search track overlap fraction sensitivity.

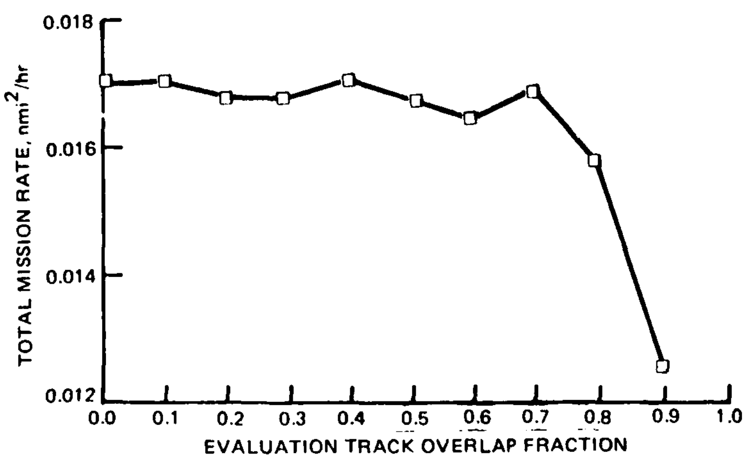

Figure B-44. Evaluation track overlap fraction sensitivity.

Figures B-41 - B-44. Baseline Towed System Middle Scenario.

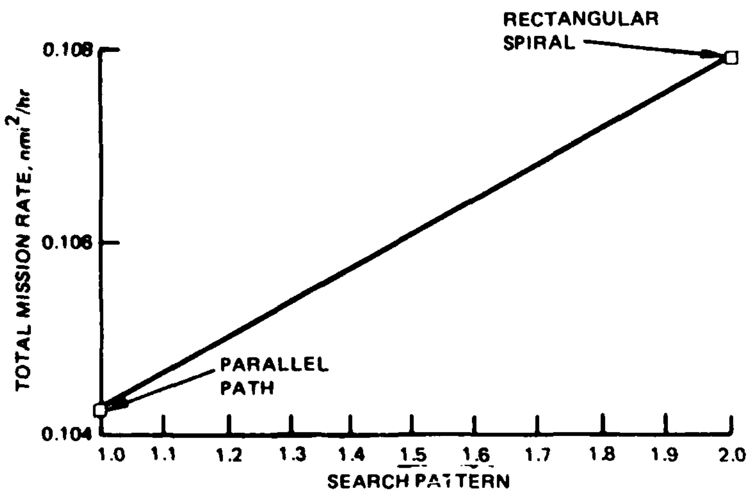

Figure B-45. Search pattern sensitivity.

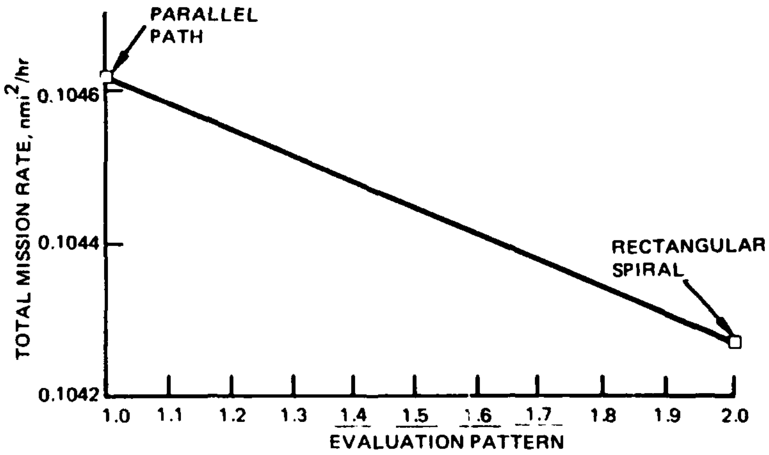

Figure B-46. Evaluation pattern sensitivity.

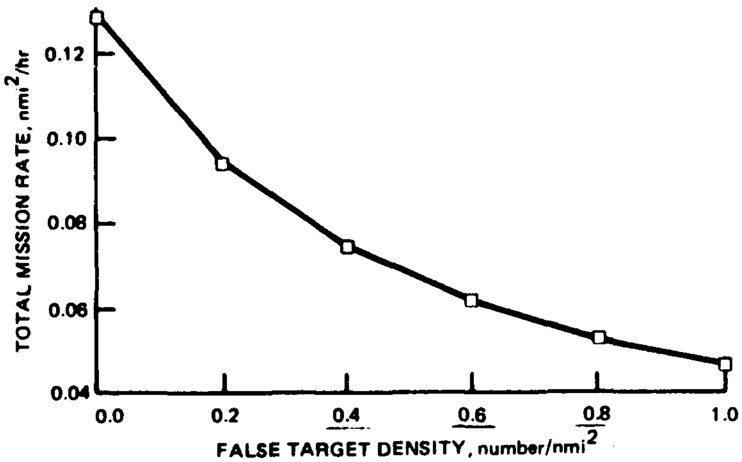

Figure B-47. False target density sensitivity.

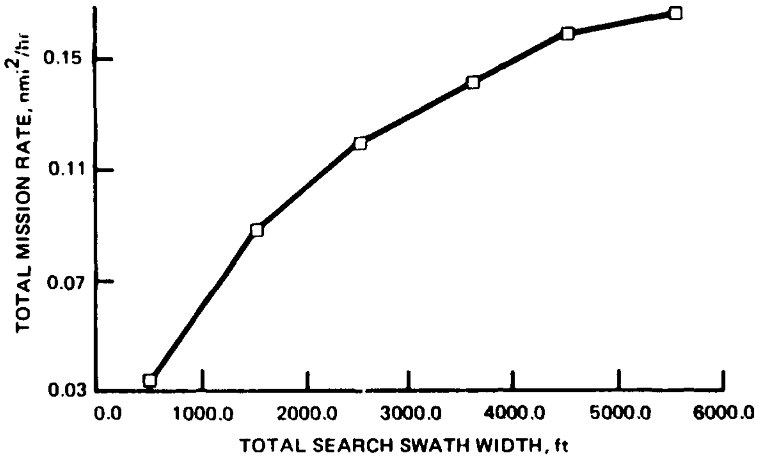

Figure B-48. Total search swath width sensitivity.

Figures B-45--B-47. Baseline Towed System Middle Scenario.
Figure B-48. Baseline Towed System Deep Scenario.

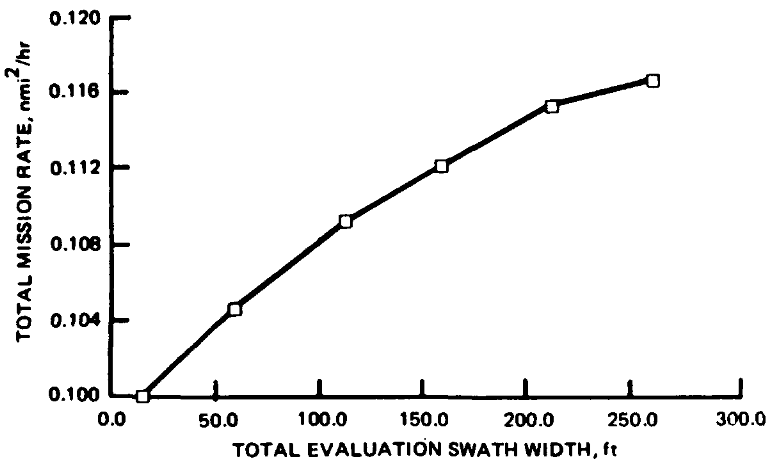

Figure B-49. Total evaluation swath width sensitivity.

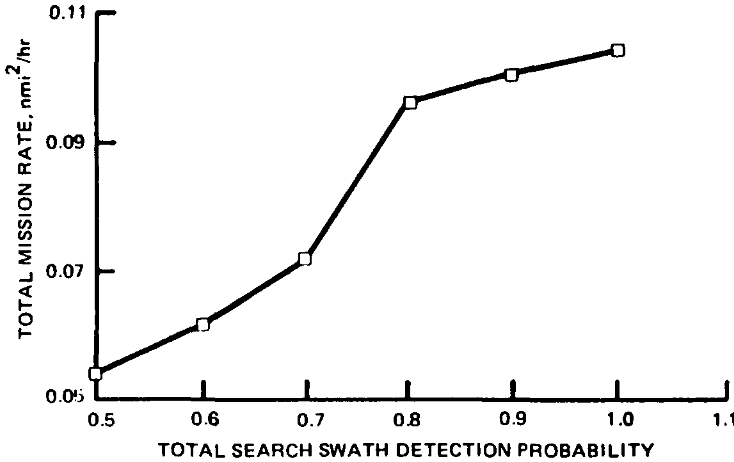

Figure B-50. Total search swath detection probability sensitivity.

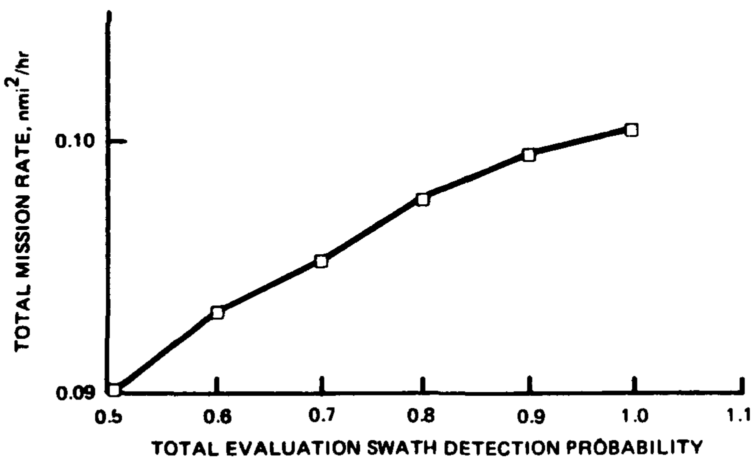

Figure B-51. Total evaluation swath detection probability sensitivity.

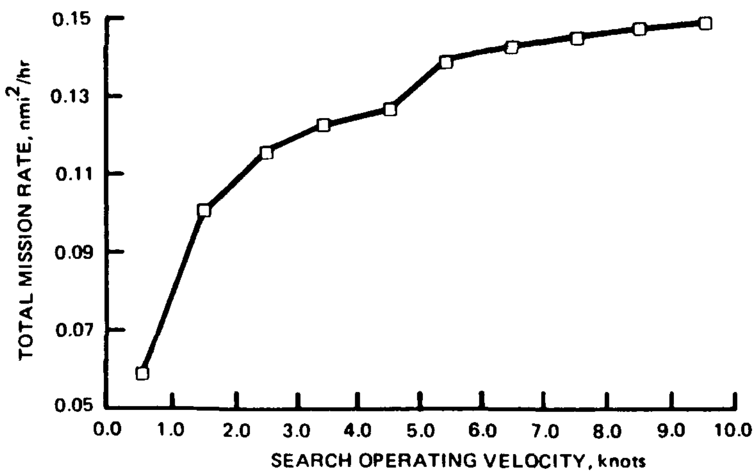

Figure B-52. Search operating velocity sensitivity.

Figures B-49 – B-52. Baseline Towed System Deep Scenario.

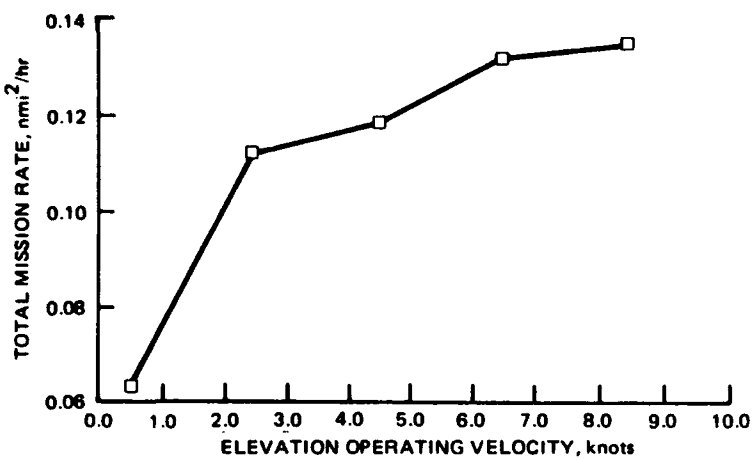

Figure B-53. Evaluation operating velocitysensitivity.

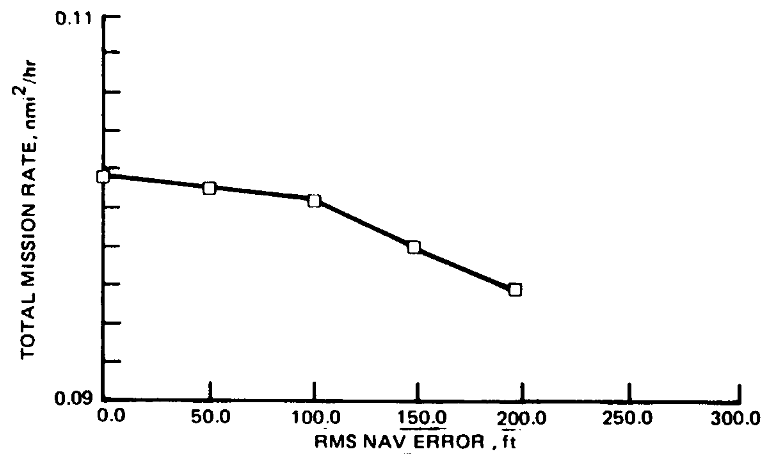

Figure B-54. Rms navigation error sensitivity.

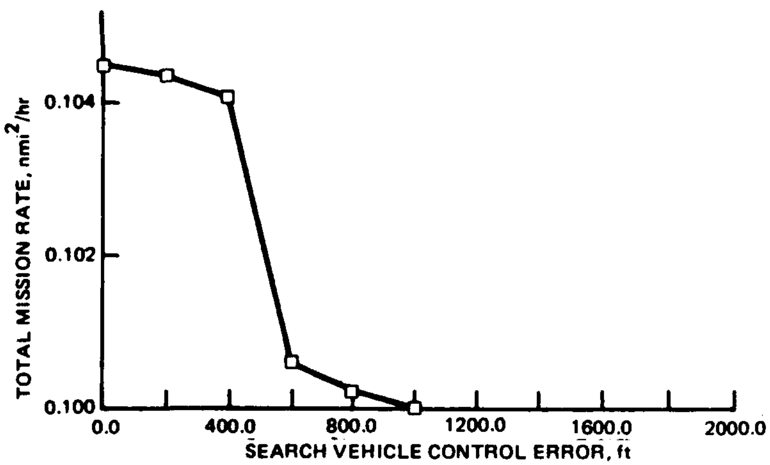

Figure B-55. Search vehicle control error sensitivity.

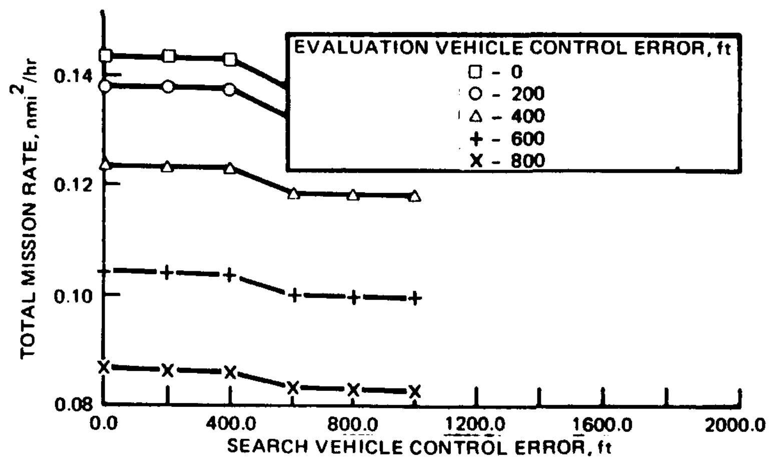

Figure B-56. Search vehicle control error/parameters sensitivity.

Figures B-53–B-56. Baseline Towed System Deep Scenario.

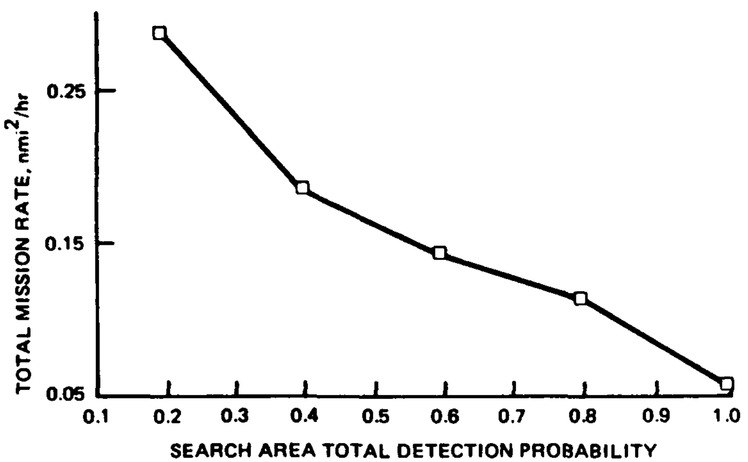

Figure B-57. Search area total detection probability sensitivity.

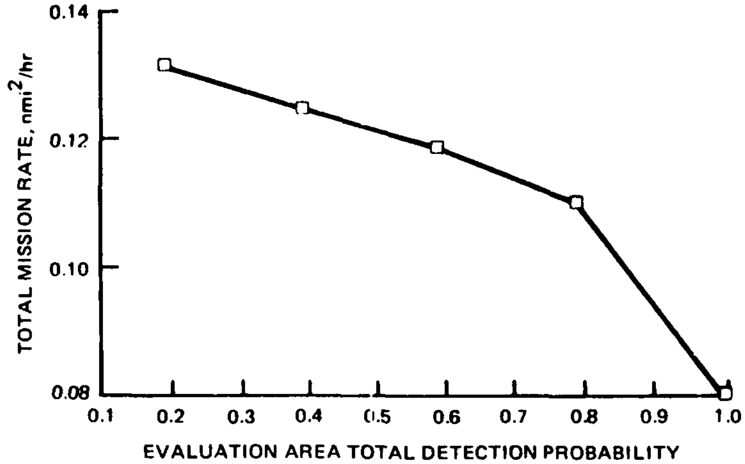

Figure B-58. Evaluation area total detection probability sensitivity.

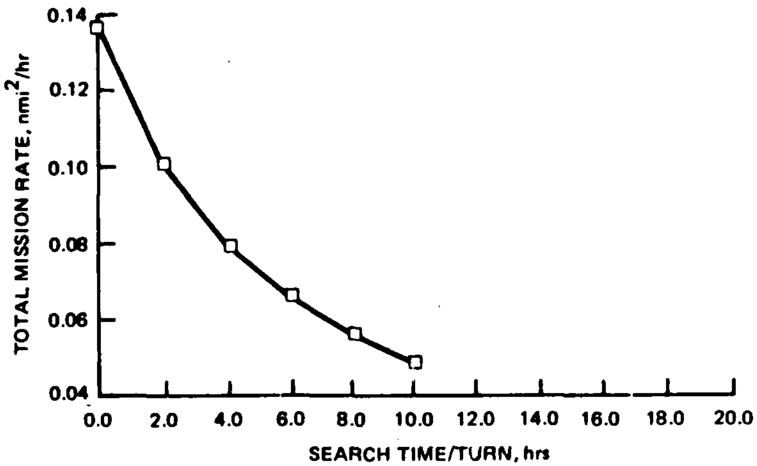

Figure B-59. Search time/turn sensitivity.

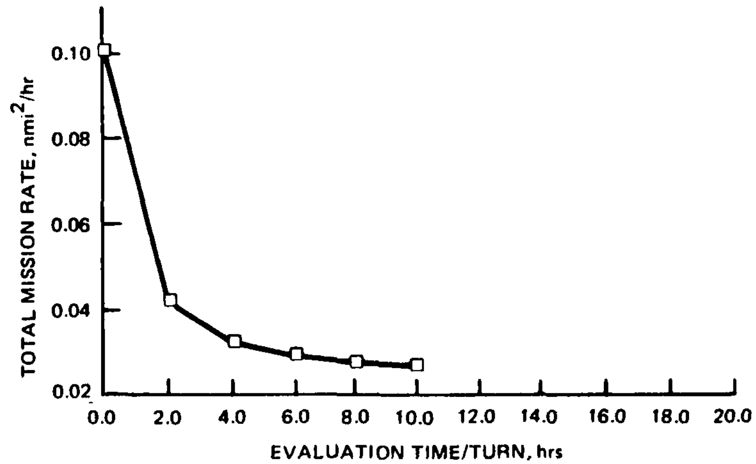

Figure B-60. Evaluation time/turn sensitivity.

Figure B-57–B-60. Baseline Towed System Deep Scenario.

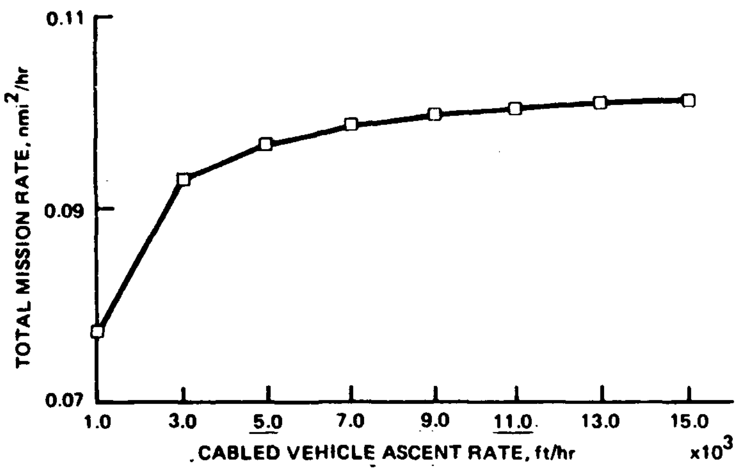

Figure B-61. Cabled vehicle ascent rate sensitivity.

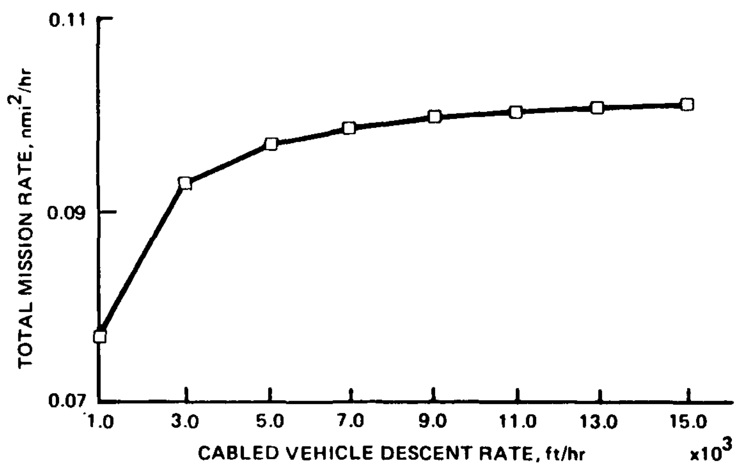

Figure B-62. Cabled vehicle descent rate sensitivity.

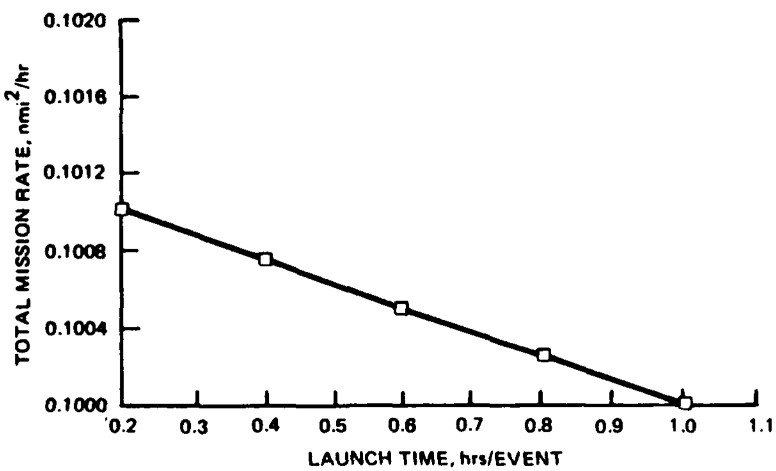

Figure B-63. Launch time sensitivity.

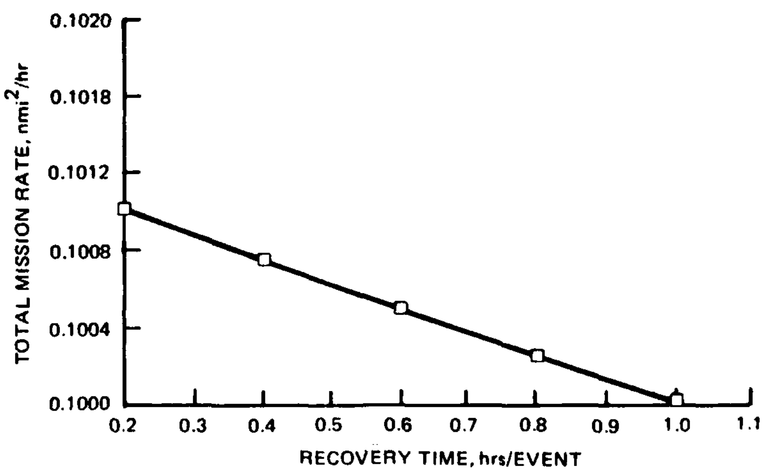

Figure B-64. Recovery time sensitivity.

Figures B-61 – B-64. Baseline Towed System Deep Scenario.

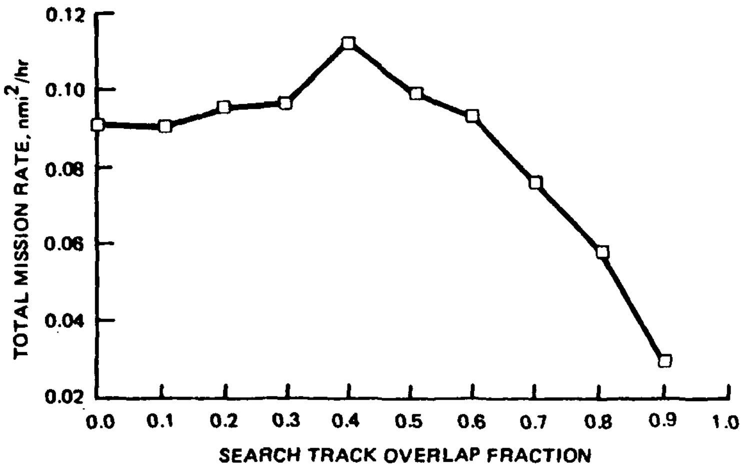

Figure B-65. Search track overlap fraction (I) sensitivity.

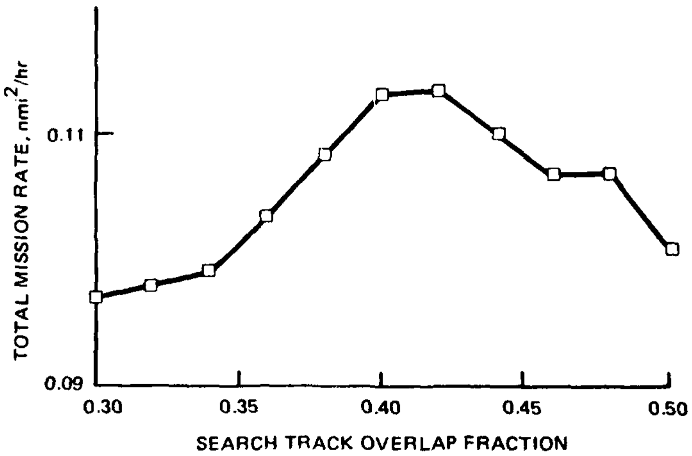

Figure B-66. Search track overlap fraction (II) sensitivity.

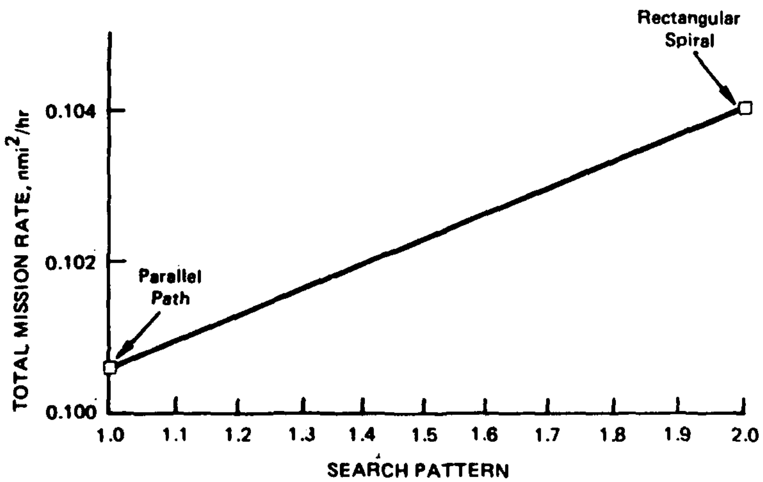

Figure B-67. Search pattern sensitivity.

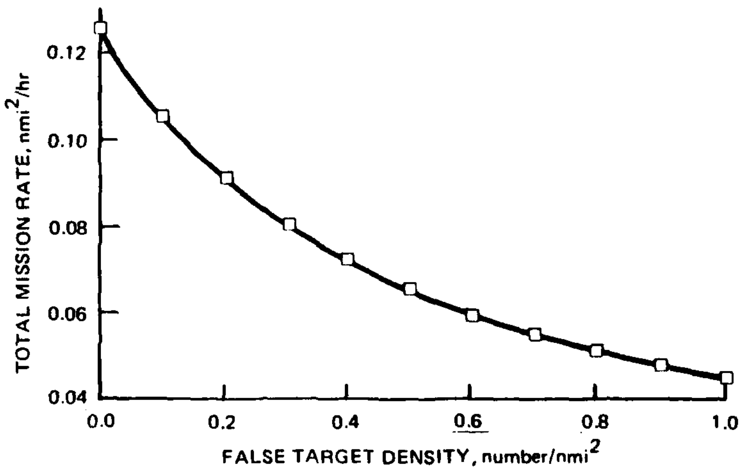

Figure B-68. False target density sensitivity.

Figures B-65–B-68. Baseline Towed System Deep Scenario.

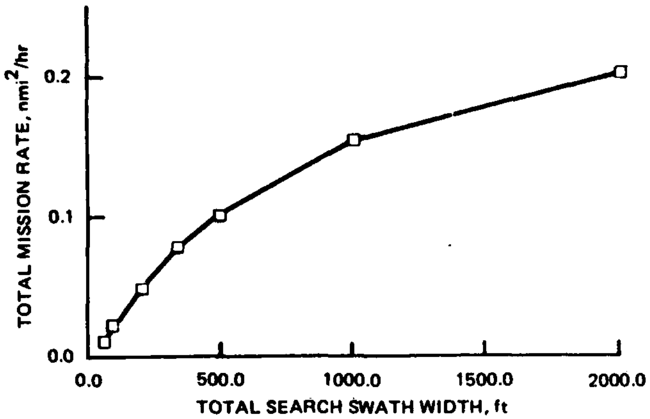

Figure B-69. Total search swath width sensitivity.

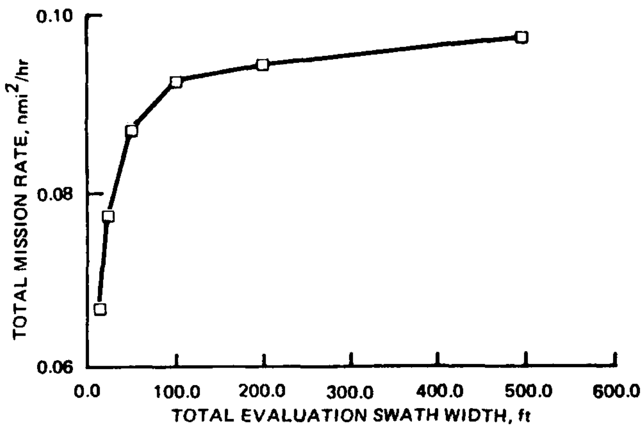

Figure B-70. Total evaluation swath width sensitivity.

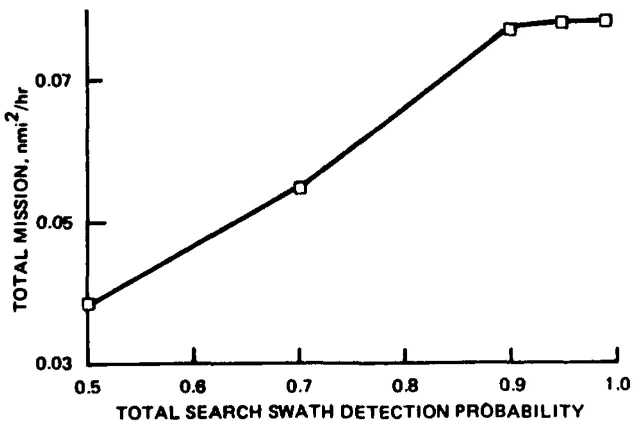

Figure B-71. Total search swath detection probability sensitivity.

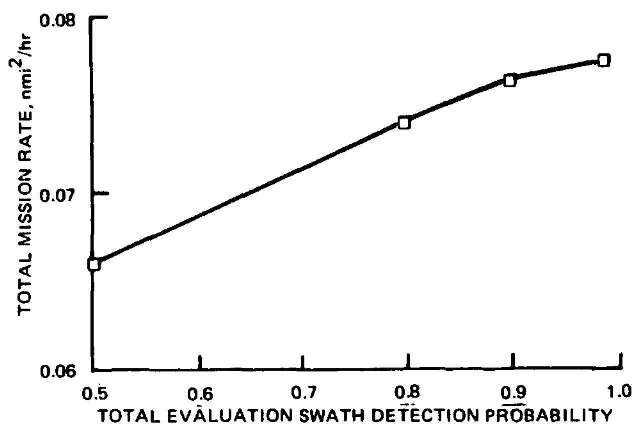

Figure B-72. Total evaluation swath detection probability sensitivity.

Figures B-69 – B-72. Free-Swimmer Shallow Scenario.

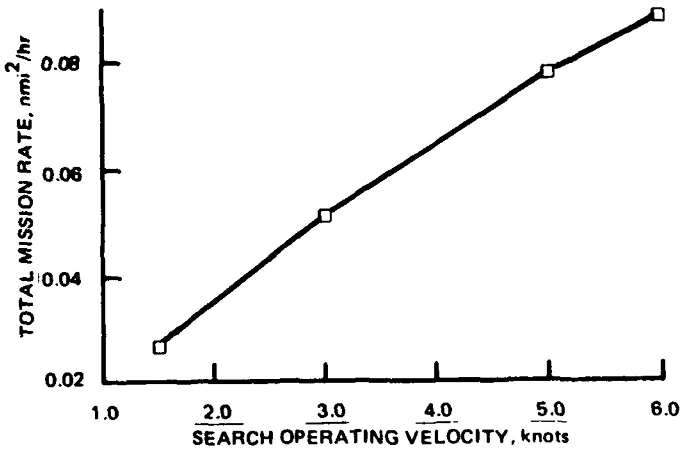

Figure B-73. Search operating velocity sensitivity.

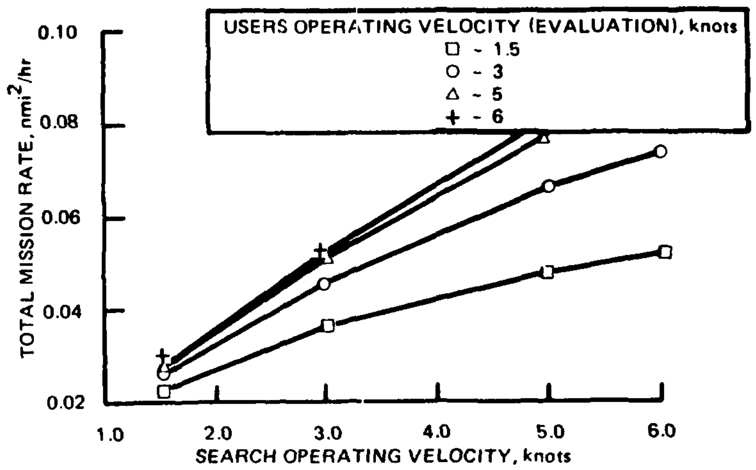

Figure B-74. Search operating velocity/parameters sensitivity.

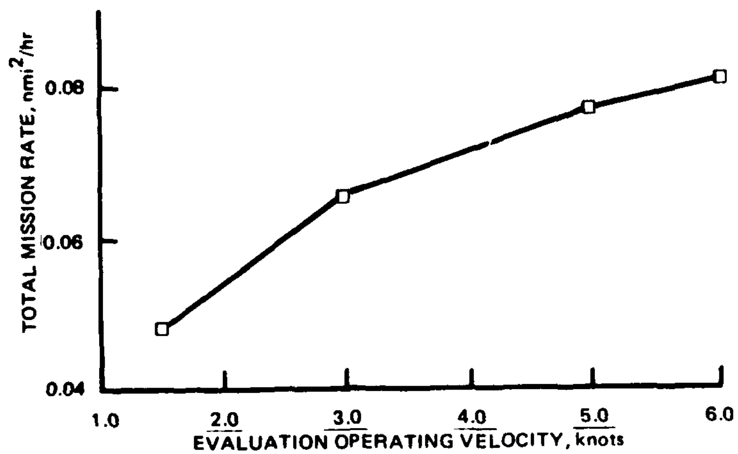

Figure B-75. Evaluation operating velocity sensitivity.

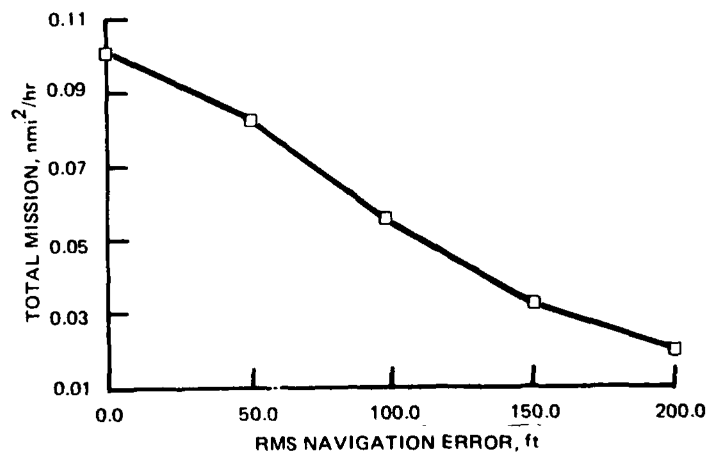

Figure B-76. Rms navigation error sensitivity.

Figures B-73—B-76. Free-Swimmer Shallow Scenario.

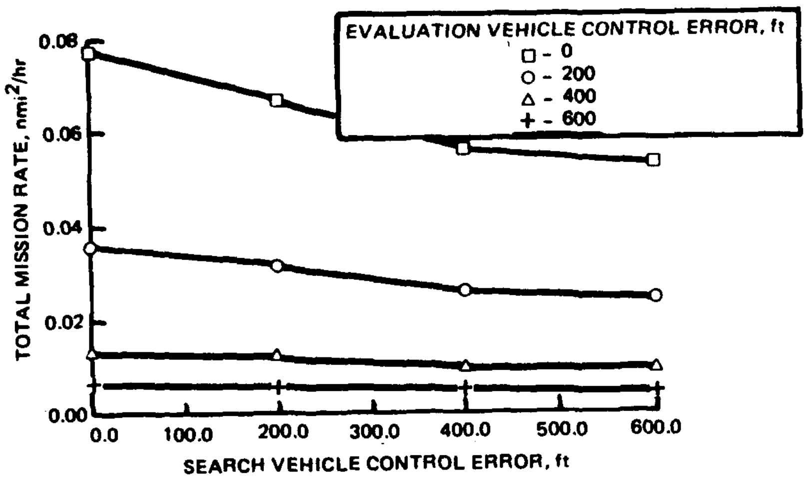

Figure B-77. Search vehicle control error/parameters sensitivity.

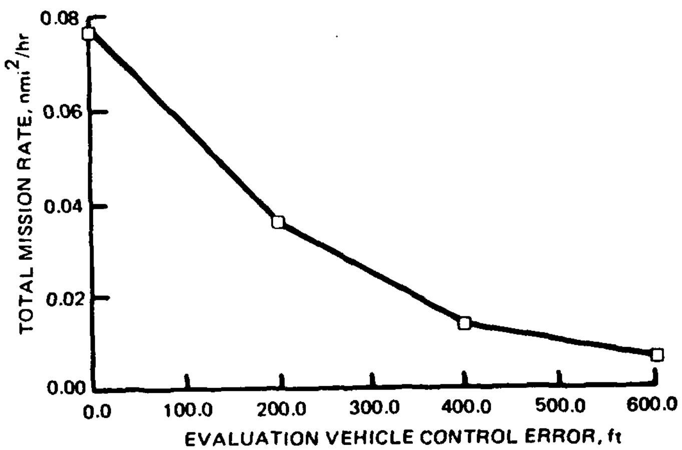

Figure B-78. Evaluation vehicle control error sensitivity.

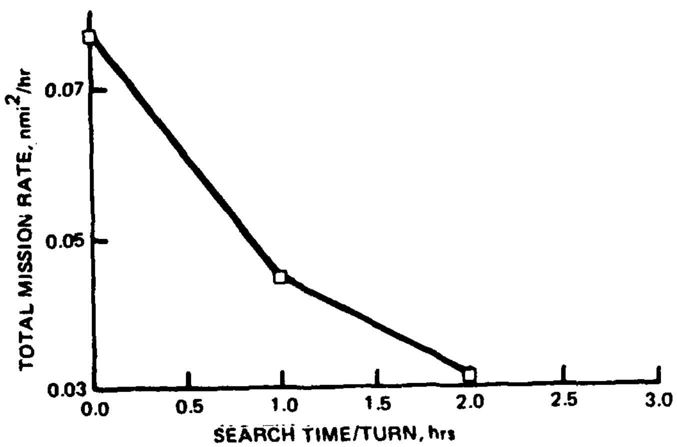

Figure B-79. Search time/turn sensitivity.

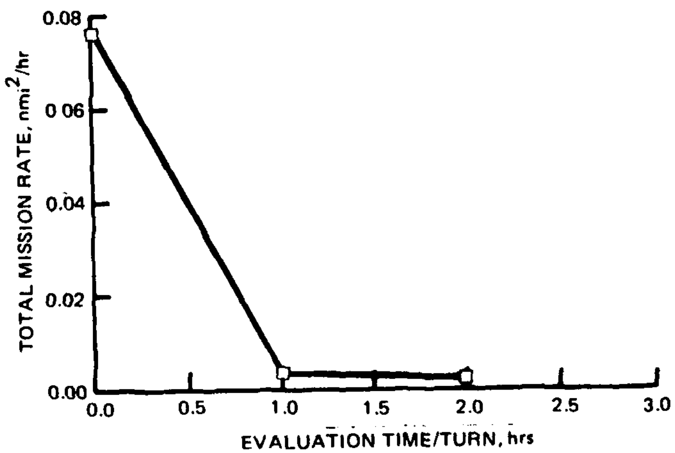

Figure B-80. Evaulation time/turn sensitivity.

Figures B-77–B-80. Free-Swimmer Shallow Scenario.

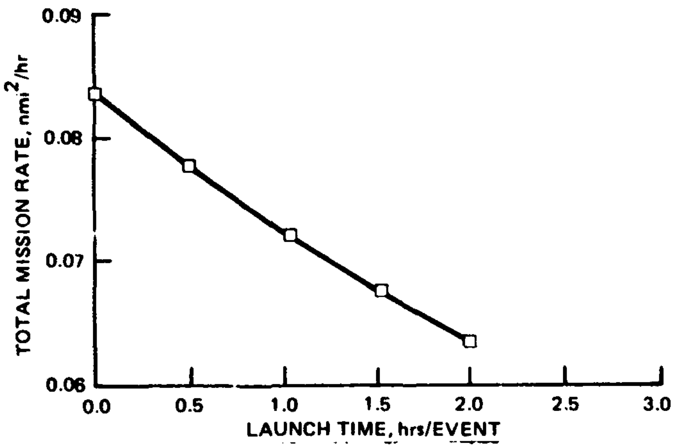

Figure B-81. Launch time sensitivity.

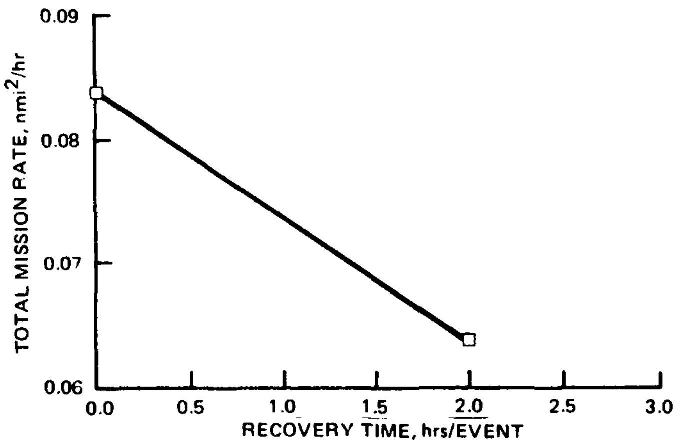

Figure B-82. Recovery time sensitivity.

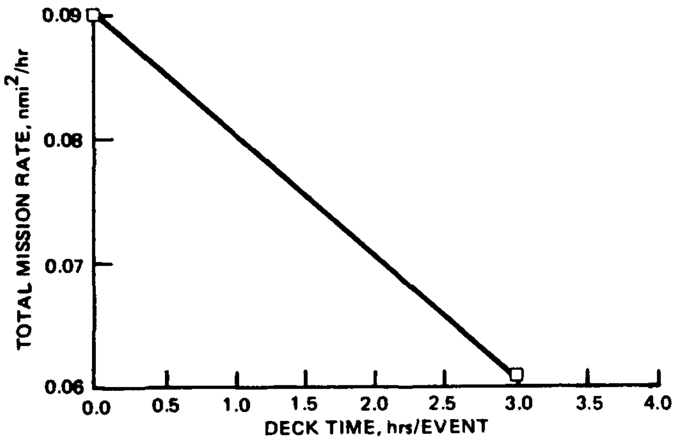

Figure B-83. Deck time sensitivity.

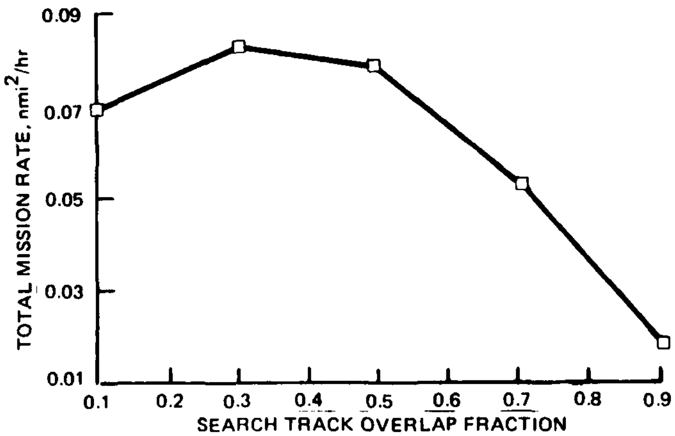

Figure B-84. Search track overlap fraction sensitivity.

Figures B-81 – B-84. Free-Swimmer Shallow Scenario.

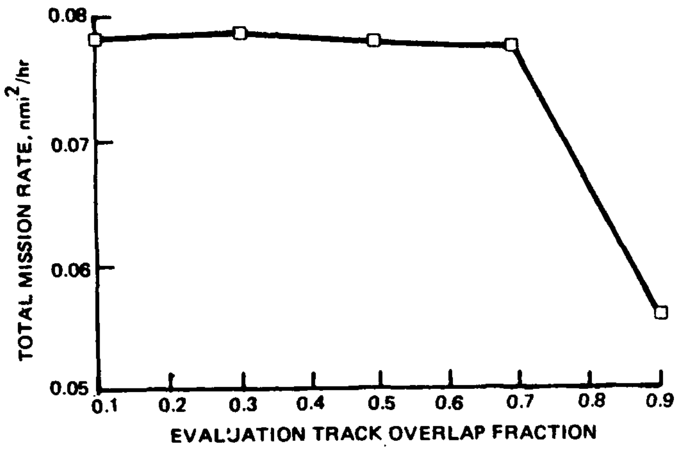

Figure B-85. Evaluation track overlap fraction sensitivity.

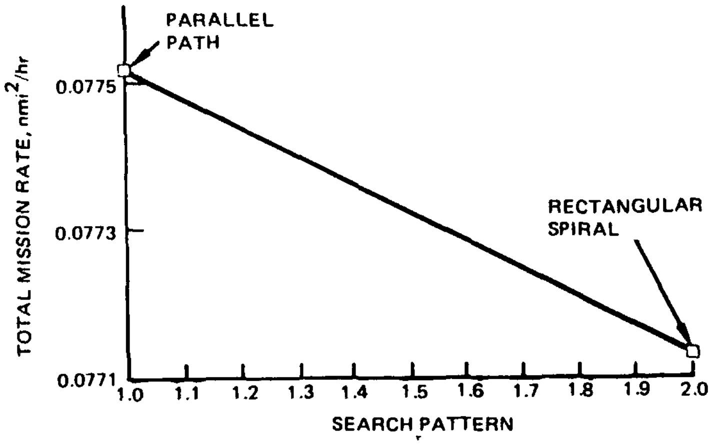

Figure B-86. Search pattern sensitivity.

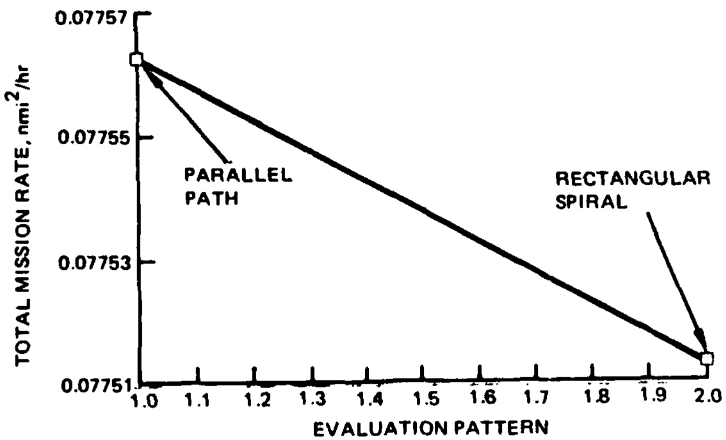

Figure B-87. Evaluation pattern sensitivity.

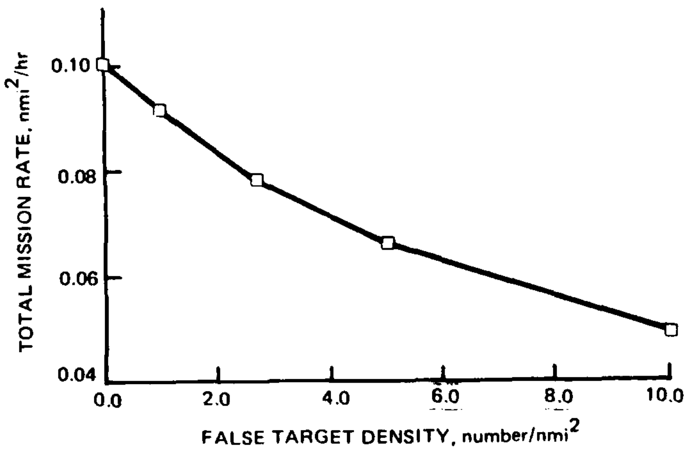

Figure B-88. False target density sensitivity.

Figures B-85–B-88. Free-Swimmer Middle Scenario.

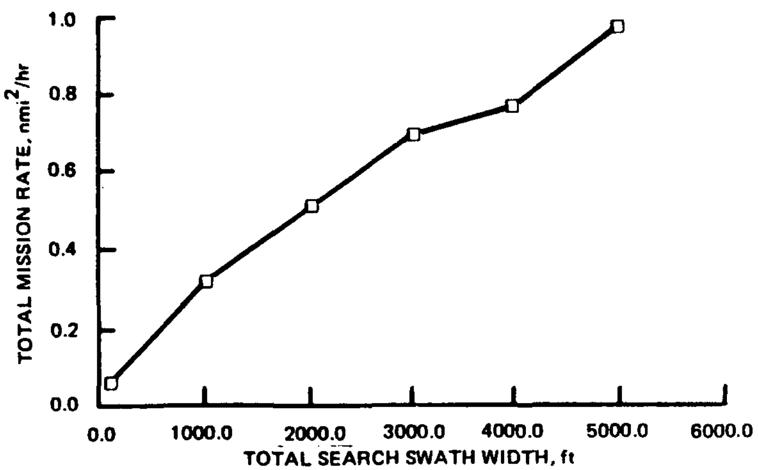

Figure B-89. Total search swath width sensitivity.

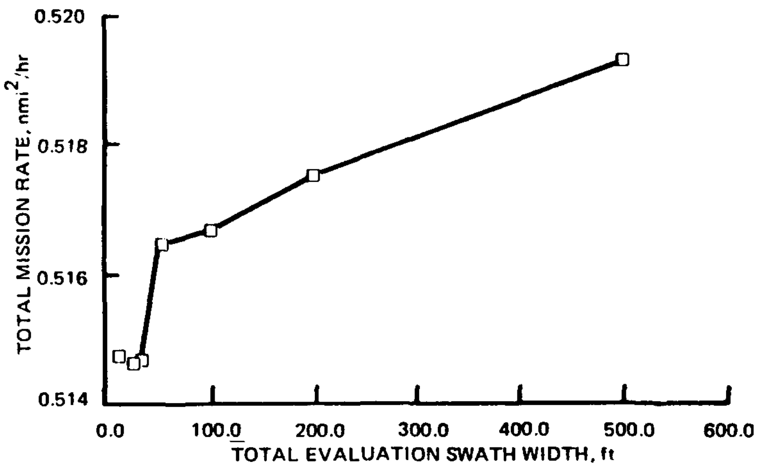

Figure B-90. Total evaluation swath width sensitivity.

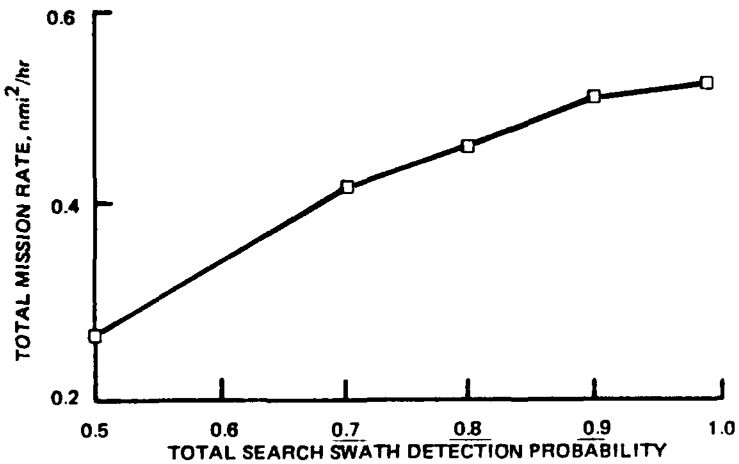

Figure B-91. Total search swath detection probability sensitivity.

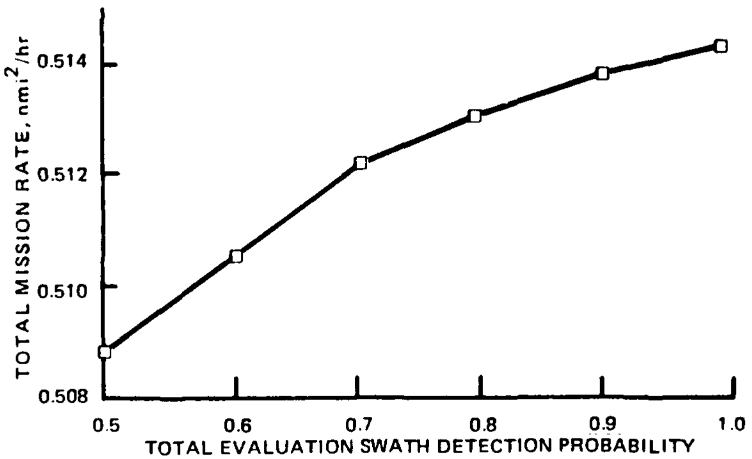

Figure B-92. Total evaluation swath detection probability sensitivity.

Figures B-89 – B-92. Free-Swimmer Middle Scenario.

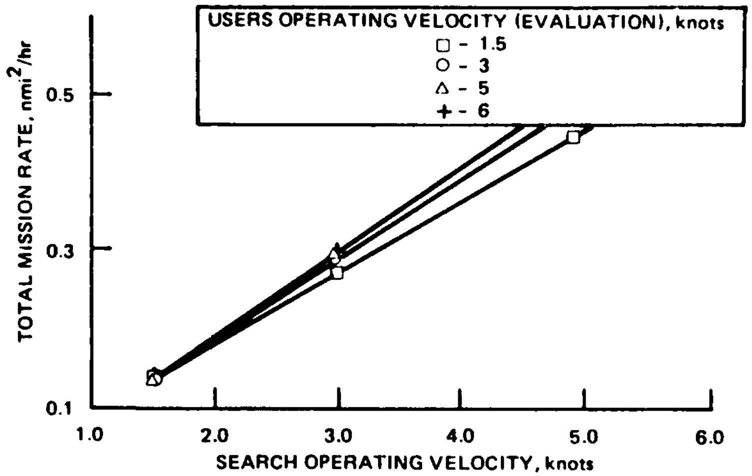

Figure B-93. Search operating velocity/parameters sensitivity.

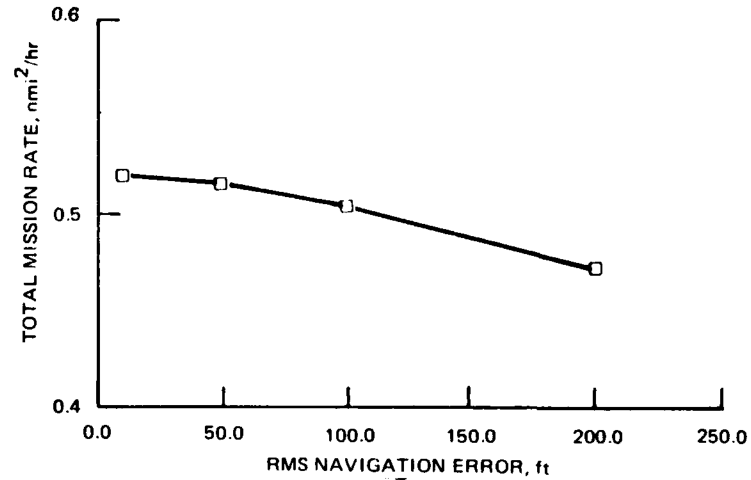

Figure B-94. Rms navigation error sensitivity.

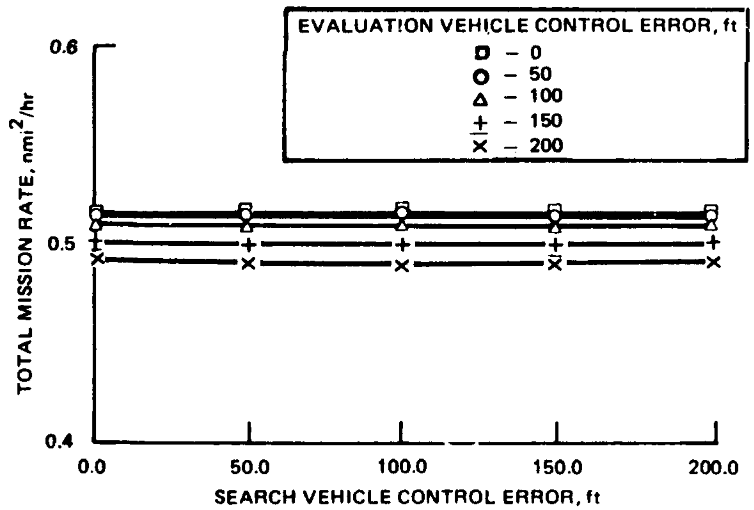

Figure B-95. Search vehicle control error/parameters sensitivity.

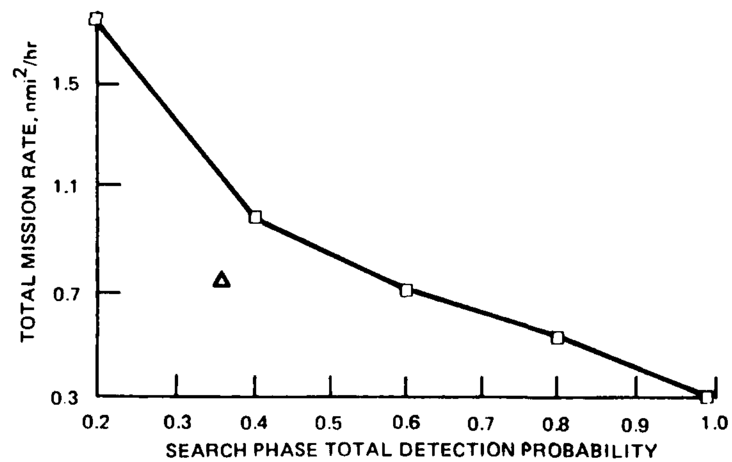

Figure B-96. Search phase total detection probability sensitivity.

Figures B-93–B-96. Free-Swimmer Middle Scenario.

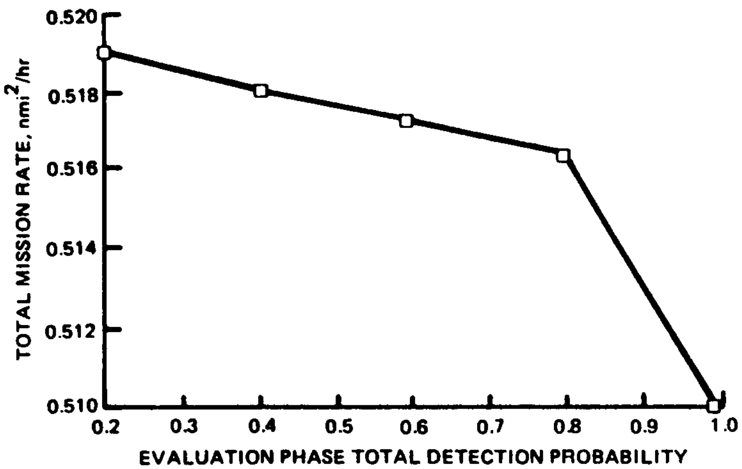

Figure B-97. Evaluation phase total detection probability sensitivity.

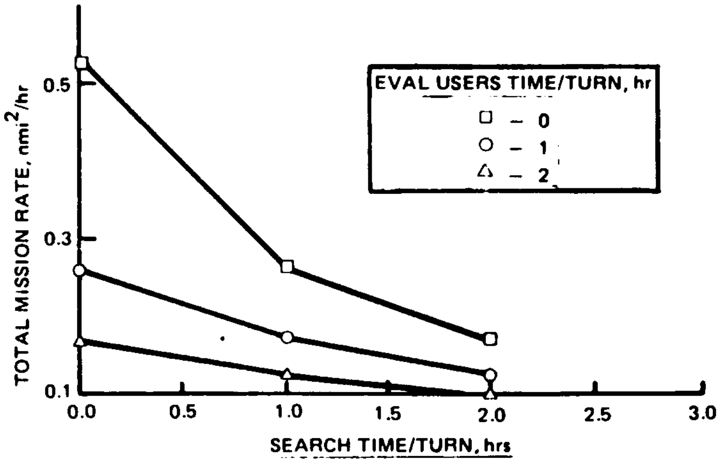

Figure B-98. Search time/turn/parameters sensitivity.

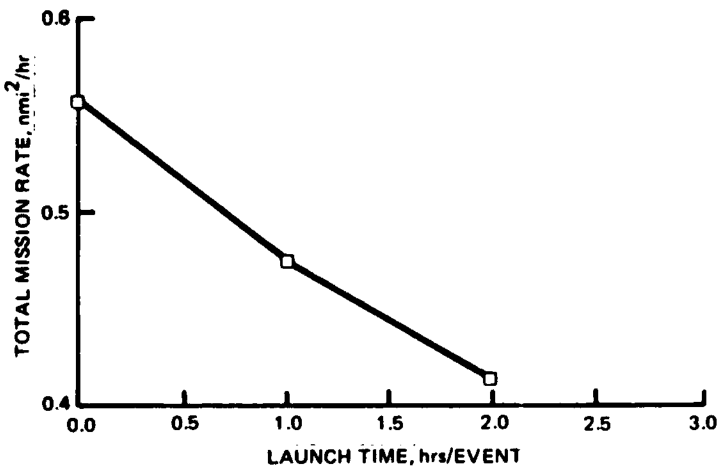

Figure B-99. Launch time sensitivity.

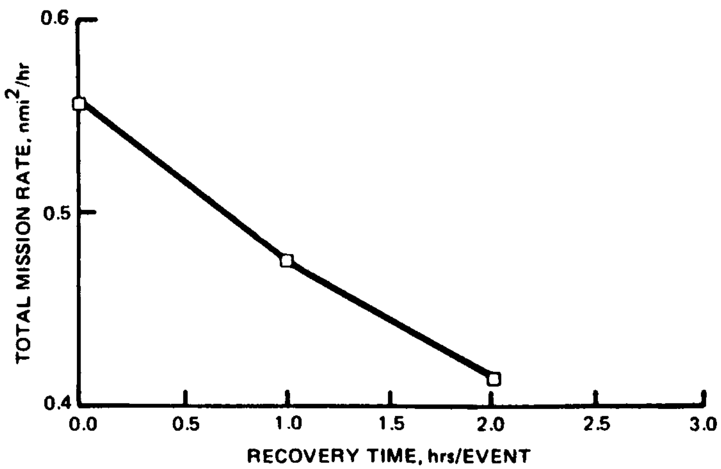

Figure B-100. Recovery time sensitivity.

Figures B-97 – B-100. Free-Swimmer Middle Scenario.

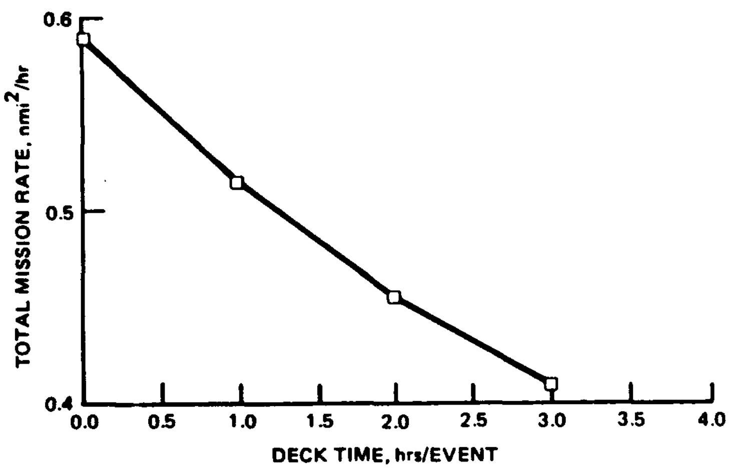

Figure B-101. Deck time sensitivity.

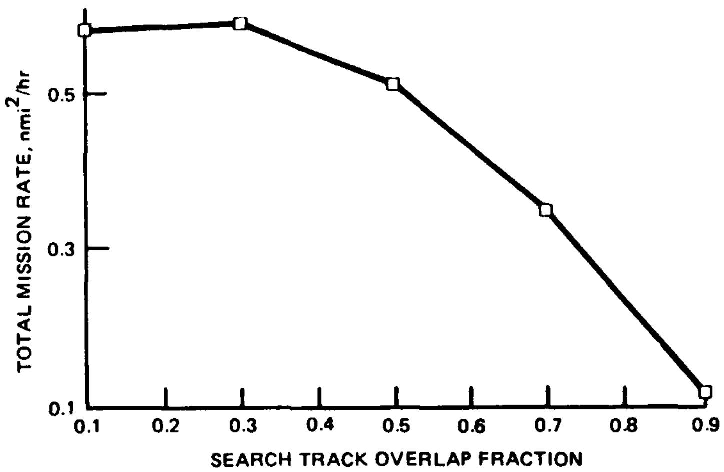

Figure B-102. Search track overlap fraction sensitivity.

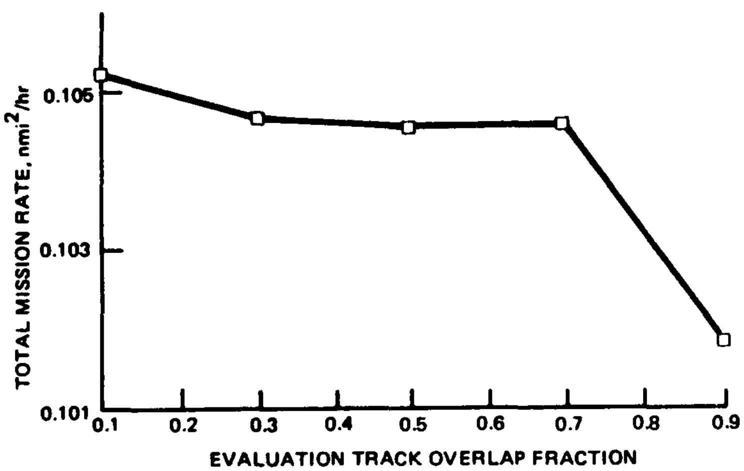

Figure B-103. Evaluation track overlap fraction sensitivity.

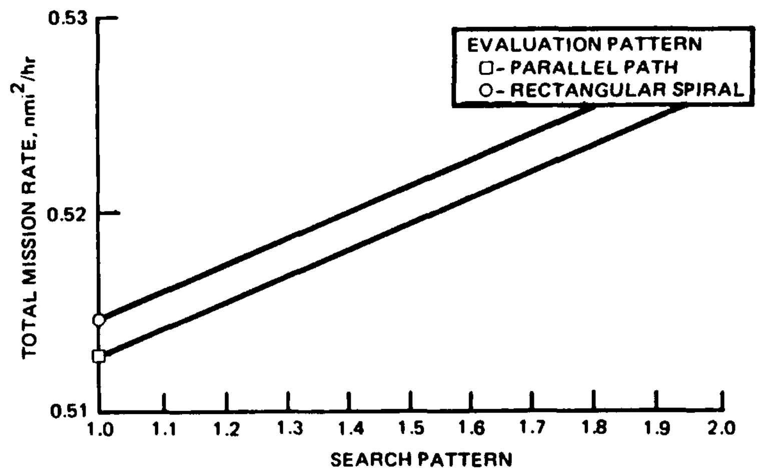

Figure B-104. Search pattern/parameters sensitivity.

Figures B-101 – B-104. Free-Swimmer Middle Scenario.

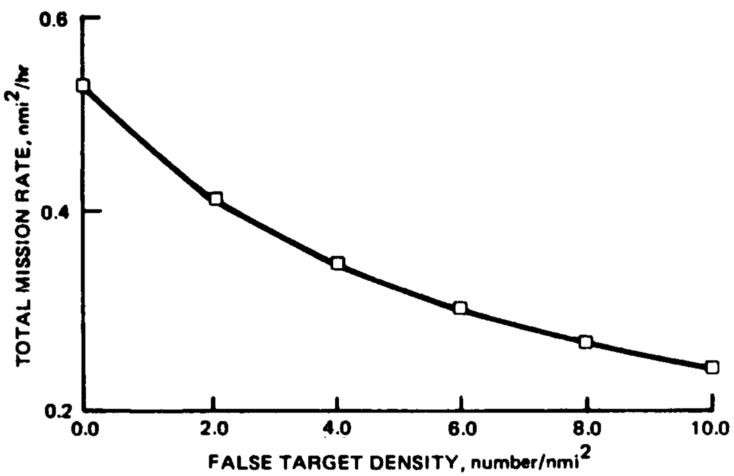

Figure B-105. False target density sensitivity.

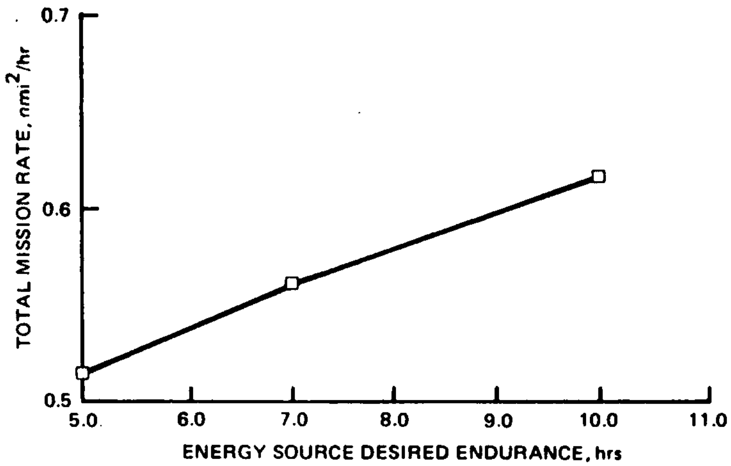

Figure B-106. Energy source endurance sensitivity.

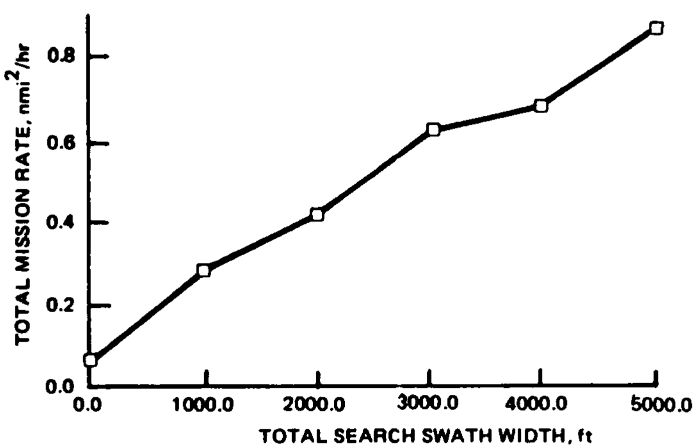

Figure B-107 Total search swath width sensitivity.

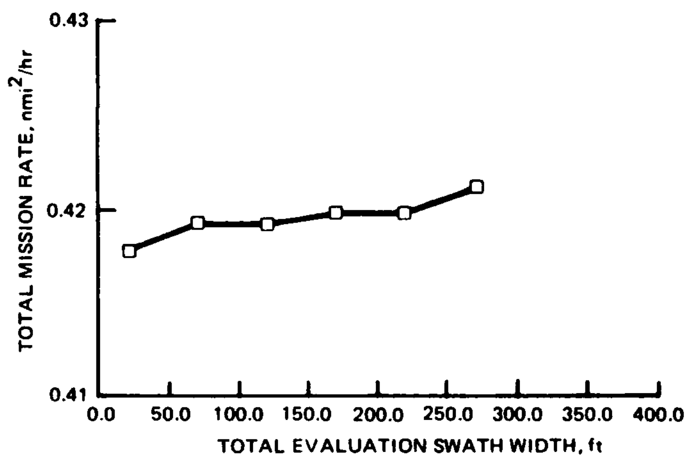

Figure B-108. Total evaluation swath width sensitivity.

Figures B-105 and B-106. Free-Swimmer Middle Scenario.
Figures B-107 and B-108. Free-Swimmer Deep Scenario.

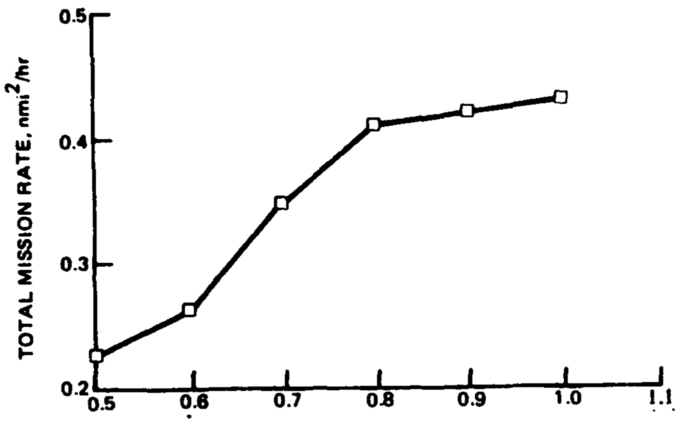

Figure B-109. Total search swath detection probability sensitivity.

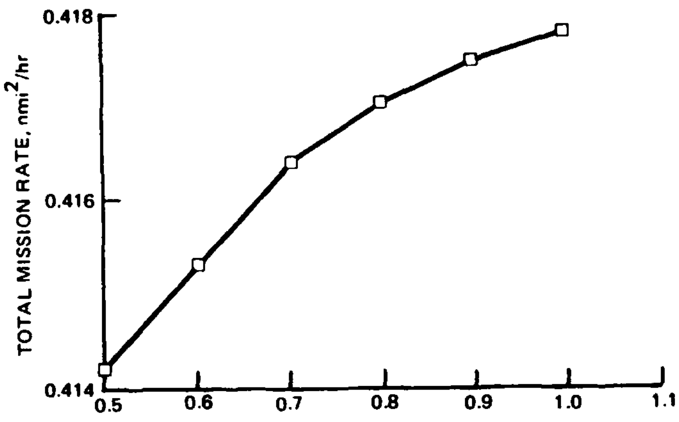

Figure B-110. Total evaluation swath detection probability sensitivity.

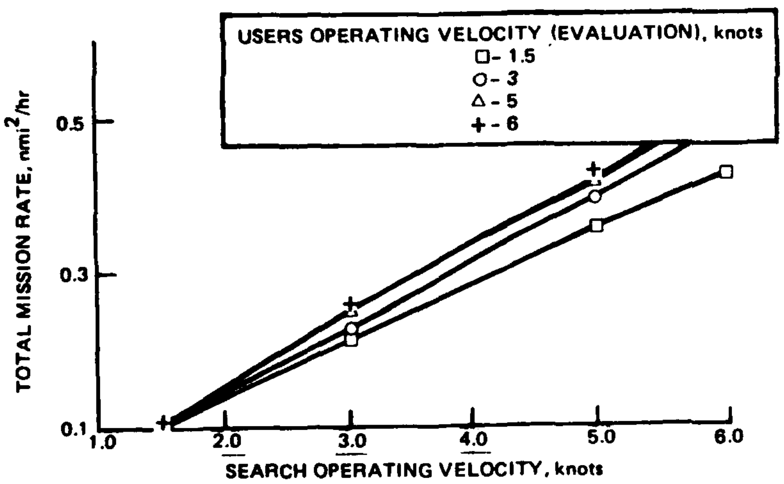

Figure B-111. Search operating velocity/parameter sensitivity.

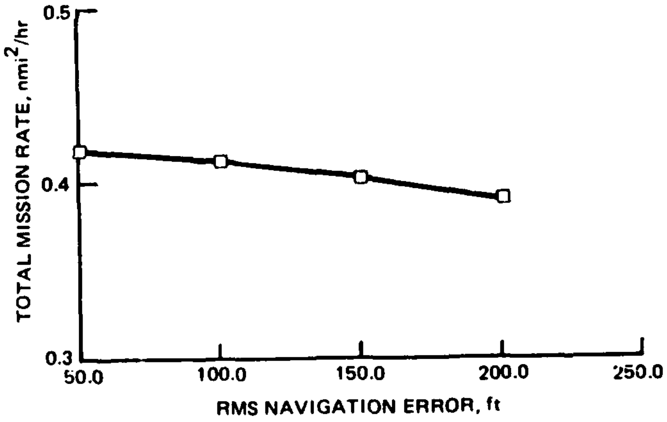

Figure B-112. Rms navigation error sensitivity.

Figures B-109–B-112. Free-Swimmer Middle Scenario.

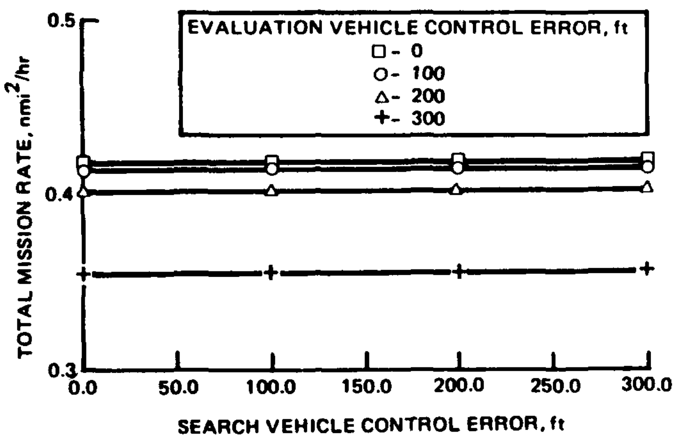

Figure B-113. Vehicle control error/parameters sensitivity.

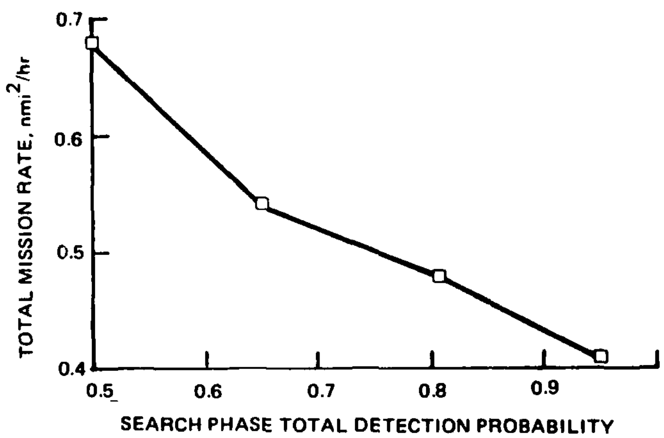

Figure B-114. Search phase total detection probability sensitivity.

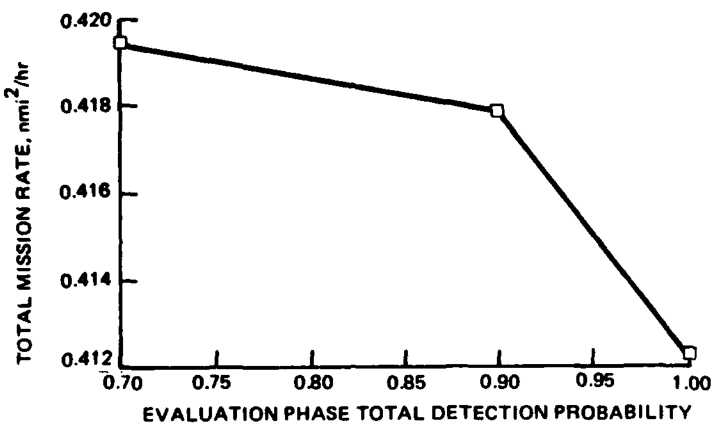

Figure B-115. Evaluation phase total detection probability sensitivity.

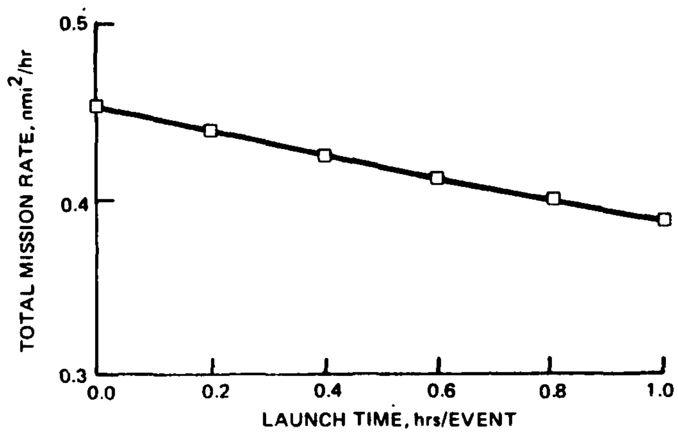

Figure B-116. Launch time sensitivity.

Figures B-113–B-116. Free-Swimmer Deep Scenario.

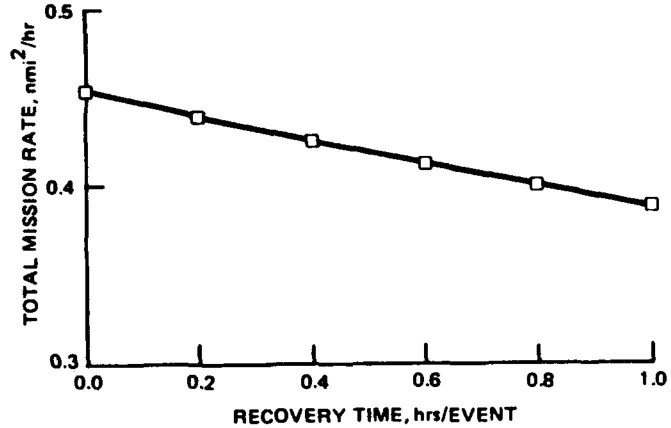

Figure B-117. Recovery time sensitivity.

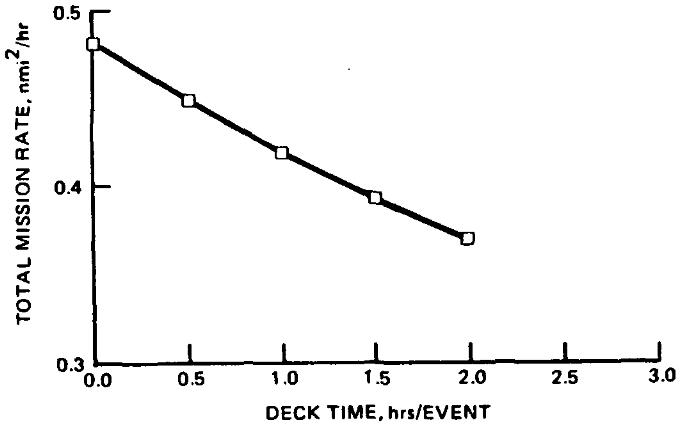

Figure B-118. Deck time sensitivity.

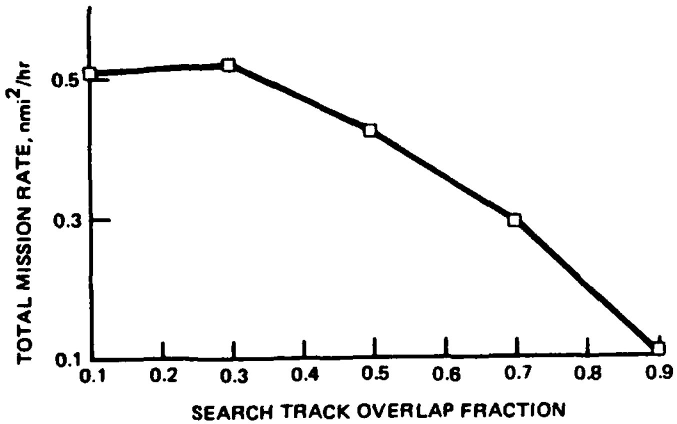

Figure B-119. Search track overlap fraction sensitivity.

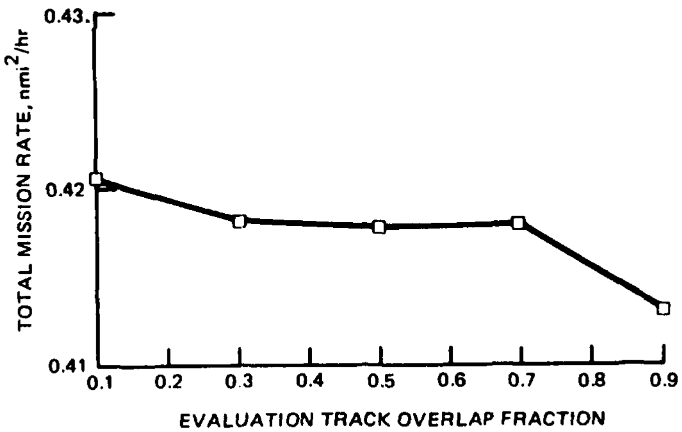

Figure B-120. Evaluation track overlap fraction sensitivity.

Figures B-117–B-120. Free-Swimmer Deep Scenario.

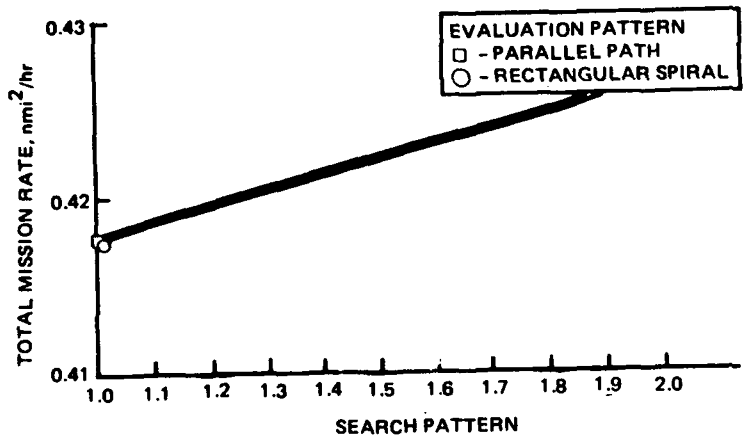

Figure B-121. Search pattern/parameters sensitivity.

Figure B-122. False target density sensitivity.

Figures B-121–B-122. Free-Swimmer Deep Scenario.

APPENDIX C
DERIVATION OF MEAN TIME EQUATIONS FOR A FREE-SWIMMING VEHICLE*

One approach to searching an area is to conduct a broad-area (e.g., sonar) search of the entire area, then to return and perform contact evaluation (e.g., video) on all promising sonar contacts. The disadvantage to this approach is obvious: there is a finite probability that the target will be detected by the sonar very early in its search, and that the remainder of the search is therefore wasted. The problem is particularly serious when the broad-area search takes a long time. (Some scenarios evaluated during the Sensitivity Analysis called for searches on the order of hundreds of hours; what if the target had been detected in the first hour?)

The opposite extreme is to perform a contact evaluation on each sonar contact as it appears. Unfortunately, there are penalties involved in this approach. For towed systems, time is wasted (because of turn times) in changing phases from the search to evaluation mode. For simple free-swimmers (those relying on recorded data), time is wasted in surfacing for the review of data tapes (plus installation of new tapes, fresh batteries, etc.).

Clearly, there must be some middle approach, an optimum strategy that weighs the probability of early detection against the penalties of immediate contact evaluation. This appendix derives this optimum strategy, developing a general set of mean performance time equations. Although the example discussed below is for the simple free-swimmer, the formulas can be equally applied to towed systems. Specific applications are derived in Appendix D.

INTRODUCTION

Let T be the time required to search and evaluate an area A so that the probability of having found the object by time T is p_d. Let the area be divided into N sub-areas which are searched sequentially by the free-swimmer (the free-swimmer surfaces for review of data after each sub-area is searched or evaluated). The time t devoted to each sub-area is then

$$t = \frac{T}{N} + T_u \qquad (1)$$

where T_u is the up-down time. (If the area is both searched and evaluated, T_u is therefore the sum of two ascents, two descents, two launches, two recoveries, and two inspections of data.) This appendix will derive formulas for three quantities:

(1) $\bar{T}$, the mean time to find the object, given that the object is found with certainty in a single coverage of the area A

(2) T_{exp}, the mean time to find the object, given that the search continues until the object is found

(3) N', the optimum value for N, the value of N that minimizes T_{exp}.

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*Formulas that appear in this appendix were developed and provided by Dr. Alan Gordon of NOSC.

$\bar{T}$, THE MEAN TIME TO FIND AN OBJECT WHEN IT IS FOUND ON A SINGLE PASS

Let T_n be the time it takes to search n sub-areas. From equation 1, we have

$$T_n = n \cdot t \tag{2}$$

$$T_n = n\left(\frac{T}{N} + T_u\right). \tag{3}$$

(Note that this is not the only poss .e expression for T_n for a simple free-swimmer, and it is not the same expression one would use for a towed system. The trick in deriving T_{exp} and N′ for any given system and search strategy is to form the proper expression for T_n. Several different expressions are formed in Appendix D.) Since it is equally likely that the object is found in any sub-area, if we let p_n be the probability that it resides in the nth sub-area we have

$$p_n = \frac{1}{N}. \tag{4}$$

Then,

$$\bar{T} = \sum_{n=1}^{N} T_n \, p_n \tag{5}$$

$$\bar{T} = \sum_{n=1}^{N} T_n \left(\frac{1}{N}\right) \tag{6}$$

$$\bar{T} = \sum_{n=1}^{N} n \cdot t \left(\frac{1}{N}\right) \tag{7}$$

$$\bar{T} = t\left(\frac{1}{N}\right) \sum_{n=1}^{N} n = t\left(\frac{1}{N}\right)\left[\frac{N(N+1)}{2}\right] \tag{8}$$

since $\sum_{n=1}^{N}$ n is n triangular. Using the expression for t from equation 1,

$$\bar{T} = \left(\frac{N+1}{2}\right)\left(\frac{T}{N} + T_u\right). \tag{9}$$

T_{exp}, MEAN TIME TO FIND TARGET

Now assume that the area A is searched repeatedly until the target is found. The mean time T_{exp} is then given by

$$T_{exp} = \sum_{m=1}^{\infty} p_m \, \overline{T}_m, \tag{10}$$

where now p_m is the probability of finding it on the mth search of A and $\overline{T}_m$ is the average time spent searching when the object is found on the mth search. Recalling that p_d is the detection probability after a single pass we have

$$p_m = \left(1 - p_d\right)^{m-1} p_d \tag{11}$$

since, in order to find the object on the mth pass, it isn't found on the first (m − 1) passes. Also,

$$\overline{T}_m = (m-1)\,(T_{pass}) + \overline{T} \tag{12}$$

where T_{pass} is the time to search all of A to p_d. For the simple free-swimmer example used in this case,

$$T_{pass} = (T + NT_u) \tag{13}$$

and therefore

$$\overline{T}_m = (m-1)\,(T + NT_u) + \overline{T} \tag{14}$$

since, in order to find the object on the mth pass, the area is completely searched (m − 1) times and then the expected time $\overline{T}$ on the mth (final) pass.

Substituting equations 1 and 14 into 10, we get

$$T_{exp} = p_d \sum_{m=1}^{\infty} (1 - p_d)^{m-1} \left\{ (m-1)\,(T + NT_u) + \overline{T} \right\} \tag{15}$$

$$\vdots$$

$$T_{exp} = p_d \,\overline{T} + p_d(1-p_d) \left\{ (T + NT_u) + \overline{T} \right\} + p_d(1-p_d)^2 \left\{ 2(T + NT_u) + \overline{T} \right\} + \ldots \tag{16}$$

Letting $T_{exp} = \xi_1 + \xi_2$, $\epsilon = 1 - p_d$, and $T_{pass} = (T + NT_u)$, we have

$$\xi_1 = p_d \,\overline{T} \left\{ 1 + (1 - p_d) + (1 - p_d)^2 + \ldots \right\}$$

$$= (1 - \epsilon)\,\overline{T} \left\{ 1 + \epsilon + \epsilon^2 + \ldots \right\}$$

$$= (1 - \epsilon)\,\overline{T} \frac{1}{(1 - \epsilon)} = \overline{T} \tag{17}$$

$$\xi_2 = p_d \, T_{pass} \, (1 - p_d) \left| 1 + 2(1 - p_d) + 3(1 - p_d)^2 + \ldots \right|$$

$$= (\epsilon)(1 - \epsilon) \, T_{pass} \left| 1 + 2\epsilon + 3\epsilon^2 + \ldots \right|$$

$$= (\epsilon)(1 - \epsilon) \, T_{pass} \frac{d}{d\epsilon} \frac{1}{(1 - \epsilon)}$$

$$= \frac{\epsilon}{1 - \epsilon} T_{pass} = \frac{1 - p_d}{p_d} (T + NT_u) \tag{18}$$

$$= \frac{1 - p_d}{p_d} T_{pass} \, . \tag{19}$$

Therefore
$$T_{exp} = \frac{1 - p_d}{p_d} (T + NT_u) + \overline{T} \tag{20}$$

or
$$T_{exp} = \frac{1 - p_d}{p_d} (T_{pass}) + \overline{T}. \tag{21}$$

Note that $T_{exp} \rightarrow \overline{T}$ as $p_d \rightarrow 1$ which is consistent with the expectation that the object will be found in the first pass with a high enough quality sensor.

N', THE VALUE OF N WHICH MINIMIZES T_{exp}

T_{exp} can be minimized by taking its derivative with respect to N and setting the result = 0. For the simple free-swimmer case examined above, one can substitute equation 9 into 20 and rearrange to find

$$T_{exp} = (T + NT_u) \left[\tfrac{1}{2}\left(1 + \frac{1}{N}\right) + \left(\frac{1 - p_d}{p_d}\right) \right] . \tag{22}$$

Taking the derivative with respect to N and setting it equal to zero yields

$$N' = \sqrt{\left(\frac{T}{T_u}\right)\left(\frac{p_d}{2 - p_d}\right)} \tag{23}$$

SUMMARY

In summary, a straightforward procedure has been developed for optimizing the number of sub-areas into which a search cell should be divided. (In simple cases, each sub-area is broad-area searched, and then all sonar contacts are evaluated before proceeding to the next sub-area.) The approach is as follows:

(1) Define T_n (the time it takes to search and evaluate n sub-areas to a detection probability p_d)

(2) Define $T_{pass} = T_{n=N}$ (the time it takes to search the entire search cell, once, to a detection probability p_d)

Table E-7. Median trailer video calculations.

(3) Define $\overline{T} = \sum_{n=1}^{N} T_n p_n$ (the mean time to find the object given that it is found on the first pass)

(4) Define $T_{exp} = \frac{(1 - p_d)}{p_d} T_{pass} + \overline{T}$ (the mean time to find the object given that the cell is searched continuously until the object is found)

(5) Set $\frac{dT_{exp}}{dN} = 0$ and solve for N. N' = N. (N' is the optimum number of subareas)

(6) Evaluate T_{exp} by letting $N = N'$.

Several applications of this procedure appear in Appendix D.

APPENDIX D
APPLICATIONS OF MEAN PERFORMANCE TIME EQUATIONS

This appendix applies the formulas of Appendix C to the cases of the baseline towed system and the seven candidate systems. All quantities will be expressed in terms output by the AUSS model: (1) T_S (the total bottom time spent to broad-area search the entire area A to p_d); (2) T_E (the total bottom time spent in contact evaluation of A to p_d); and (3) T_u (the total time spent in a *single* up-down cycle, including deck time, launch, and recovery). For all cases, $p_d = 0.9$.

BASELINE TOWED SYSTEM

The penalty for immediate contact evaluation with a baseline towed system is the time involved in changing phases (PC) from the search to evaluation mode (and back again). Applying the steps of the Appendix C summary:

$$T_n = \left[\frac{T_S + T_E}{N} + 2PC\right] n - PC + T_u \ . \tag{1}$$

Equation 1 was derived by considering the terms involved for N = 1, N = 2, N = 3, etc. It can be readily shown that equation 1 applies to all cases.

$$\bar{T} = \sum_{n=1}^{N} T_n \left(\frac{1}{N}\right)$$

$$\bar{T} = \left[\frac{T_s + T_E}{N} + 2PC\right] \left(\frac{N+1}{2}\right) + T_u - PC \tag{2}$$

$$T_{exp} = \left[\frac{1 - p_d}{p_d}\right] \left\{\left[\frac{(T_S + T_E)}{N} + 2PC\right] N - PC + T_u\right\} + \left[\frac{T_S + T_E}{N} + 2PC\right] \left(\frac{N+1}{2}\right) + T_u - PC \ . \tag{3}$$

Setting $\frac{dT_{exp}}{dN} = 0$ and solving for N,

$$N' = \left\{\frac{T_S + T_E}{PC\left[2 + 4\frac{(1 - p_d)}{p_d}\right]}\right\}^{1/2} . \tag{4}$$

The quantities T_S, T_E, and T_u are obtained from the AUSS model (with $p_d = 0.9$). PC = 2 hours for the deep case and 1 hour for the shallow case (equivalent to the baseline turn times).

OPTIMIZED TOWED SYSTEM

Equations 1 through 4 apply to this system as well. The AUSS model results will of course differ, resulting in a different final value for T_{exp}.

TOWED SYSTEM WITH DECOUPLING CLUMP

Equations 1 through 4 will apply, but this system will differ from the "optimized towed system" in the following areas:

(1) T_S will be obtained from an AUSS model run with control error = 0. This change reflects the use of the decoupling clump.

(2) T_E will be obtained from an AUSS model run with control error = 0 (same as above) plus navigation rms error = 0. The latter change reflects the use of the clump-mounted scanning sonar for use in navigating the vehicle during contact evaluation.

TOWED SYSTEM WITH TRAILER VIDEO

The towed/trailer video system differs from the above towed systems in that immediate contact evaluation is sometimes possible, with no time penalties.

First consider Case A, in which the video vehicle's excursions cover the entire sonar swath. In this case, immediate contact evaluation will always be possible (to a probability of detection p_d).

Therefore,

$$N' = 1$$

$$\bar{T} = \left(\frac{T_S}{\#ft}\right)\left(\frac{\#ft}{2} + 1\right) + T_u \tag{5}$$

where #ft = the number of false targets in A, a quantity determined from the AUSS model. The assumption is that half the total false targets in A will be detected before the actual target is detected.

Continuing,

$$T_{exp} = \left(\frac{1 - p_d}{p_d}\right)\left(T_S + T_u\right) + \left(\frac{T_S}{\#ft}\right)\left(\frac{\#ft}{2} + 1\right) + T_u \, . \tag{6}$$

Now consider Case B, in which the video vehicle's excursions only partially cover the sonar swath. In this case, the formulas and inputs for the "towed system with decoupling clump" apply, with the exception that T_E is replaced by

$$T_E = T_E \left(1 - \frac{\text{video excursion swath}}{\text{sonar swath}}\right). \tag{7}$$

Equation 7 reflects the fact that some sonar contacts are evaluated during the search phase and need not be reevaluated during the contact evaluation phase.

A rough average between Cases A and B can be formed in the following manner. Assume, as an example, that for a given scenario the vehicle excursion is 20 percent of the sonar swath. The average T_{exp} is therefore

$$\text{Average } T_{exp} = 0.2\,(T_{exp} \text{ for case A}) + 0.8\,(T_{exp} \text{ for Case B}). \qquad (8)$$

In other words, 20 percent of the time immediate contact evaluation (Case A) would be possible, 80 percent of the time it wouldn't (Case B). Table E-7 of Appendix E presents specific results for these averages.

FREE-SWIMMER

As an example, consider the case of N = 4. A possible free-swimmer strategy is as follows:

EVENTS	MISSION TIME
(1) Vehicle searches first cell and then surfaces.	$\frac{T_S}{N} + T_u$ (T_u excludes deck time in this case.)
(2) Vehicle searches second cell and then surfaces. Simultaneously, the 1st subcell search data is reviewed on deck.	$\frac{T_S}{N} + T_u$
(3) The vehicle performs contact evaluation on the 1st subcell, then searches the 3rd subcell, then surfaces. Simultaneously, the 2nd subcell search data is reviewed on deck.	$\frac{T_E}{N} + \frac{T_S}{N} + T_u$
(4) The vehicle performs contact evaluation on the 2nd subcell, then searches the 4th subcell then surfaces. Simultaneously, the 1st subcell evaluation data and the 3rd subcell search data are reviewed on deck.	$\frac{T_E}{N} + \frac{T_S}{N} + T_u$
(5) The 4th subcell data is reviewed on deck.	$\frac{T_S}{N}$
(6) The vehicle performs contact evaluation on the 3rd and 4th subcells and then surfaces.	$\frac{2T_E}{N} + T_u$

Summing the mission times for each event, the formula for N = 4 as well as all other values reduces to

$$T_n = \left[\frac{T_S + T_E}{N} + T_u\right] n + \left[\frac{T_S}{N} + T_u\right].$$

Equation 8 holds for all n.

Continuing,

$$T_{exp} = \left(\frac{1 - p_d}{p_d}\right)\left[T_S + T_E + NT_u + \frac{T_S}{N} + T_u\right] + \left[\frac{T_S + T_E}{2}\right]\left[1 + \frac{1}{N}\right] + \frac{T_u(N+1)}{2}$$

$$+ \frac{T_S}{N} + T_u . \qquad (9)$$

Setting $\frac{dT_{exp}}{dN} = 0$ and solving for N,

$$N' = \left\{\frac{T_S\left[3 + 2\left(\frac{1 - p_d}{p_d}\right)\right] + T_E}{T_u\left[1 + 2\left(\frac{1 - p_d}{p_d}\right)\right]}\right\}^{1/2} . \qquad (10)$$

Optimum battery life is therefore $\frac{T_S + T_E}{N'} + T_u$.

ACOUSTIC LINK FREE-SWIMMER

The penalty for the acoustic link free-swimmer is merely the phase change involved in changing from the search to evaluation modes, not the up-down cycle required in the simple free-swimmer (for data review). The correct formulas for the acoustic link free-swimmer are therefore equivalent to those of the towed system, with the assumptions of zero control error and a one-minute phase change. Since N′ is a function of PC rather than T_u, there is no optimum battery life as a function of N. The longer the battery life, the better the mission rate.

ACOUSTIC LINK FREE-SWIMMER/CURV TYPE SEARCH

The acoustic link free-swimmer used in the CURV-type search mode is calculated in a different manner than the above free-swimmers. There is no "N"; there are a number of scan circles determined by the area to be searched divided by the area of each sonar scan, assuming sufficient overlap to provide complete coverage.

Subsequent calculations are performed as follows.

(1) Calculate

$$\frac{T_{scanning} + T_{evaluation} + T_{transit}}{scan} = \frac{bottom\ time}{scan}$$

where

$\frac{T_{scanning}}{scan}$ = estimated time for each sonar scan, and interpretation of that scan, while hovering at the center of a scan circle. Time used in AUSS analysis: 30 seconds

$\frac{T_{transit}}{scan}$ = estimated time to transit from the center of one scan circle to the center of the next. This is simply the inter-scan distance divided by the maximum vehicle velocity.

$\frac{T_{evaluation}}{scan}$ = time spent transiting to each false target, at acoustic link sonar speed limit, plus the time to transmit and review the data for each false target, all times the number of false targets per scan. The time spent transiting to each false target and the number of false targets per cell are outputs of the AUSS model. The time to transmit and review video data from each false target was assumed to be 60 seconds. The number of scans is determined from a geometrical layout of the situation.

(2) Calculate $T_{bottom} = \left(\frac{\text{bottom time}}{\text{scan}}\right)$ (#scans)

(3) Calculate "T_u" = time for a two-way dive at maximum vehicle speed plus one launch and recovery. This time is the up-down time during which the batteries are being drained. (Deck time is excluded.)

(4) Calculate "L" = T_{bottom} + "T_u" which is equal to the total operating time assuming that only one bounce is necessary ("L" = the battery life for this case).

(5) Let L = actual battery life. (In the optimum case, L = "L.")

Calculate

$$T_{pass} = T_{bottom} + \overbrace{\left[\frac{T_{bottom}}{(L - \text{“}T_u\text{”})}\right]}^{\text{(rounded up to nearest integer)}} (T_u)$$

where T_u includes deck time (for changing batteries, etc.).

(6) Now, the time for immediate contact evaluation is equal to the time to search and evaluate all the false targets in half the scan circles plus one more target. The time for evaluating the "one more target" was determined in step (1) above (under "$T_{evaluation}$/scan").

Calculate

$$\overline{T}_{\text{immediate bottom time}} = \left(\frac{\#\text{scans}}{2}\right)\left(\frac{\text{bottom time}}{\text{scan}}\right) + \left(\begin{array}{c}\text{time per}\\ \text{1 false}\\ \text{target}\end{array}\right)$$

(7) Calculate

$$\overline{T}_{\text{immediate total}} = \overline{T}_{\substack{\text{immediate}\\ \text{bottom}\\ \text{time}}} + \overbrace{\left(\frac{\overline{T}_{\text{immediate bottom time}}}{L - \text{“}T_u\text{”}}\right)}^{\text{rounded up to nearest integer}} (T_u)$$

(8) Finally,

$$T_{exp} = \left(\frac{1 - p_d}{p_d}\right)\left(T_{pass}\right) + \overline{T}_{\text{immediate total}}$$

RF TETHER LINK/CURV TYPE SEARCH

It was assumed that the bottom time for this system would be limited by the length of wire in each spool (50,000 feet) rather than by battery life. The number of subcells per search cell (a function of cable length) and the number of sonar scans per subcell (a function of sonar capability) are determined from geometrical considerations (see Appendix E).

The expected performance time for this system was performed as follows.

(1) Calculate

$$\frac{\text{bottom time}}{\text{scan}}$$

and

$$\frac{\text{bottom time}}{\text{each false target}}$$

as per step (1) of the "Acoustic Link Free-Swimmer/CURV Type Search."

(2) Calculate

$$T_{\text{bottom}} = \left(\frac{\text{bottom time}}{\text{scan}}\right) (\#\text{scans})$$

where # scans is $\left(\frac{\text{subcells}}{\text{cell}}\right)\left(\frac{\text{scans}}{\text{subcell}}\right)$.

(3) Calculate

$$T_{\text{pass}} = T_{\text{bottom}} + \left(\frac{\text{subcells}}{\text{cell}}\right) (T_u)$$

where T_u is 15 minutes longer than the value used in the above cases, to account for the additional object (buoy) in the water.

(4) Immediate contact evaluation is performed, with the assumption that all the false targets in half the scan circles plus one more target are to be evaluated before the target is found.

Calculate

$$\overline{T}_{\text{immediate bottom time}} = \left(\frac{\#\text{scans}}{2}\right)\left(\frac{\text{bottom time}}{\text{scan}}\right) + \left(\frac{\text{bottom time}}{\text{false target}}\right)$$

(5) Calculate

$$\overline{T}_{\text{immediate total}} = \overline{T}_{\substack{\text{immediate}\\ \text{bottom time}}} + \overset{\text{rounded up to nearest integer}}{\left[\frac{\left(\frac{\text{scans}}{2}\right)}{\left(\frac{\#\text{scans}}{\text{subcell}}\right)}\right]} (T_u)$$

(6) Calculate

$$T_{\text{exp}} = \left(\frac{1 - p_d}{p_d}\right) T_{\text{pass}} + \overline{T}_{\text{immediate total.}}$$

APPENDIX E
INITIAL AND INTERIM VALUES

This appendix contains tables of initial and interim values generated during the performance analysis of the baseline towed system and the seven candidate systems. This detail is provided so that specific system-to-system differences will be apparent and to justify the choices of certain values.

SYSTEM INPUT SUMMARY

Table E-1 summarizes the initial values used for the systems subjected to AUSS model analysis. Note that only five of the eight systems were modeled directly on the computer. Results for the towed system with trailer video, the rf tether link/CURV type search, and the acoustic link free-swimmer/CURV type search were generated by inserting AUSS model results from the modeled systems into the performance equations of Appendices C and D.

Superscripts in Table E-1 refer the reader to notes that justify the particular values used. Items without superscripts were drawn from the baseline or state-of-the-art values listed in Tables 2–4 (main body of report). Sonar swaths were drawn from Table E-3, and track overlap fractions were obtained by optimizing that value on the AUSS model after all other parameters had been optimized.

VIDEO SPEED LIMIT

In situations where it is necessary for an operator to monitor video data real time, there is an upper limit to the speed at which the camera can fly over the ocean floor. To the operator, excessive speeds can induce motion sickness or can reduce the passing scene to an indecipherable blur. To avoid these effects, the camera was assumed to capture a sequence of scenes, allowing the operator 2 seconds to inspect each frame. (In the case of slow scan television, 8 seconds were allowed per frame.) Given the forward swath of the camera (derived from the lateral swath according to a 4:3 aspect ratio), the maximum forward speed can therefore be derived for any of these situations. Table E–2 summarizes these speed limits.

SONAR SWATHS/SPEEDS

Sonar swaths and maximum speeds were calculated by the AUSS model from basic sonar parameters (beamwidth, frequency, etc.), using parameters associated with the baseline towed system's side-looking sonar without a center gap. For the 300-foot target/deep scenario (only), parameters associated with an MPL side-looking sonar were used. Table E–3 presents the swath width and maximum speeds calculated for these sonars. Forward speed is a function of target length (3 pings or hits required in the deep scenario, 20 hits in shallow).

ACOUSTIC LINK SPEED LIMITATIONS

Acoustic link sonar speed limitations were set in accordance with the current NOSC acoustic link transmission rate of $(120)^2$ data points per 8 seconds. Consider the deep scenario case with a 10-foot target. The resolution required is 3.33 feet (3 hits per 10-foot target). The number of data points per ping, assuming one data point per resolution element, is

Table E-1. System input summary.

Variables	Systems							
	(Run) Baseline Towed	(Run) Optimized Towed	(Run) Towed/ Clump	Towed/ T. Video	Rf Tether Link	(Run) Free-Swimmer	(Run) A. Link FS	A. Link FS CURV search
Search nav error, ft	≈60	15	15	15	15	15	15	15
Evaluation nav error, ft	≈60	15	0	0	0	15	15	0
Search control error, ft	600	200	0	0	0	0	0	0
Evaluation control error, ft	100	100	0	0	0	0	0	0
Search pattern	parallel path	rect spiral	rect spiral	rect spiral	"circles"	rect spiral	rect spiral	"circles"
Evaluation pattern	rect spiral	rect spiral	rect spiral[1]	Immed or reduc. swath[2]	direct[3]	rect spiral	rect spiral	direct[3]
Search turn time, hours	2	0	0	0	0	0	0	0
Evaluation turn time, hours	1	0	0	0	0	0	0	0
Launch time, hours	.5	.25	.25	.25	.5	.25	.25	.25
Deep search speed, knots								
10 - ft target	1.5	4.54[4]	4.54			4.54	4.54[4]	
30 - ft target	1.5	5.64[4]	5.64			5.64	5.64	
100 - ft target	1.5	6[5]	6			10[7]	10	
300 - ft target	1.5	6	6			10	10	
Deep evaluation speed, knots								
10 - ft target	1.5	3[6]	3			10[7]	3.06[9]	
30 - ft target	1.5	3	3			10	3.06	
100 - ft target	1.5	3	3			10	3.06	
300 - ft target	1.5	3	3			10	3.06	
Shallow search speed, knots								
10 - ft target	1.5	4.25[4]	4.25			4.25[4]	0.81[9]	
30 - ft target	1.5	4.25	4.25			4.25	2.43[9]	
100 - ft target	1.5	4.25	4.25			4.25	4.25	
300 - ft target	1.5	9.4[5]	9.4			10[7]	10	
Shallow evaluation speed, knots								
10 - ft target	1.5	3[6]	3			6.74[8]	1.68[9]	
30 - ft target	1.5	3	3			6.74	1.68	
100 - ft target	1.5	3	3			6.74	1.68	
300 - ft target	1.5	3	3			6.74	1.68	
Deep sonar swath, ft								
10 - ft target	2201	2201	2201			2201	2201	
30 - ft target	5310	5310	5310			5310	5310	
100 - ft target	5310	5310	5310			5310	5310	
300 - ft target	5310	6995	6995			6995	6995	
Deep video swath, ft	21.8	55	55			55	55	

Table E-1. System input summary (Continued).

Variables	Systems							
	(Run) Baseline Towed	(Run) Optimized Towed	(Run) Towed/ Clump	Towed/ T. Video	Rf Tether Link	(Run) Free-Swimmer	(Run) A. Link FS	A. Link FS CURV search
Shallow search swath, ft								
10 - ft target	330	330	330			330	330	
30 - ft target	990	990	990			990	990	
100 - ft target	3302	3302	3302			3302	3302	
300 - ft target	3413	3413	3413			3413	3413	
Shallow evaluation swath, ft	21.8	30.2	30.2			30.2	30.2	
Cable drag coefficient	1.7	.13	.13	.13	–	–	–	–
Deep search overlap fraction								
10 - ft target	.40	.15	.5			.5		
30 - ft target	.20	.15	.5			.5		
100 - ft target	.20	.15	0.0			0.0		
300 - ft target	.30	.35	0.0			.35		
Deep evaluation overlap fraction								
10 - ft target	.25	.15	0.0			.30		
30 - ft target	0.0	.20	0.0			.20		
100 - ft target	.10	.30	0.0			.55		
300 - ft target	.40	0.0	0.0			.55		
Shallow search overlap fraction								
10 - ft target	.45	.40	.10			.10		
30 - ft target	.20	.20	.10			.10		
100 - ft target	.15	.15	.15			.20		
300 - ft target	.20	.40	.20			.20		
Shallow evaluation overlap fraction								
10 - ft target	.20	.20	0.0			.10		
30 - ft target	.30	.15	0.0			.25		
100 - ft target	.35	.30	0.0			.45		
300 - ft target	.30	.35	0.0			.70		
Phase change deep, hours	2.0	2.0	2.0	–	–	–	.0167	–
Phase change shallow, hours	1.0	1.0	1.0	–	–	–	.0167	–

Notes:

[1] A rectangular spiral contact evaluation was performed as an approximation to the direct target-to-target transits that would be performed with this system.

[2] As above, a rectangular spiral pattern was chosen as an approximation. For the delayed evaluation case, fewer contacts were evaluated in keeping with the capabilities of the trailing video vehicle.

[3] Times for evaluating and transmitting data were estimated, with times for transiting from target-to-target calculated.

[4] These are sonar speed limits for these target sizes. See Table E-3.

[5] This is a tow-speed limit, the speed at which a faired cable will trail behind the tow ship at the same angle that an unfaired cable will trail for a speed of 1.5 knots.

[6] Available data indicates that the tow ship will have to circle at approximately four times the rate of the fish in this mode. Assuming an upper limit of 12 knots for the tow ship in this mode, an upper limit of 3 knots for the vehicle was assessed.

[7] 10 knots was selected as an upper limit for the free-swimmer, compatible with navigation system and high-speed bottom-following requirements.

[8] 6.74 knots is a physiological video limit for this case. See Table E-2.

[9] This is an acoustic link data rate limitation. See Tables E-2 (video) or E-4 (sonar).

Table E-2. Video speed limits.

Reason for Limit	Water Type	Seconds per Frame	Forward Swath per Frame, ft	Maximum Forward Speed, knots
Physiological	Deep ocean	2	41.25	12.25
Physiological	Coastal	2	22.65	6.74
Slow scan	Deep ocean	8	41.25	3.06
Slow scan	Coastal	8	22.65	1.68

Table E-3. Maximum swath width and forward speed for side-looking sonar.

Scenario	Target length, ft	Swath, ft	Maximum speed, knots
Shallow	10	330	4.25
	30	990	4.25
	100	3302	4.25
	300	3413	12.30
Deep	10	2201	4.54
	30	5310	5.64
	100	5310	18.83
	300	6995	43.73

$$\frac{\text{data points}}{\text{ping}} = \frac{2201}{3.33} = 660.9 \ .$$

(The swath for this situation was 2201 feet.) Since the forward motion is given by 3 pings = 10 feet, the maximum forward velocity is given by

$$\left(\frac{14400 \text{ data points}}{8 \text{ seconds}}\right)\left(\frac{1 \text{ ping}}{660.9 \text{ data points}}\right)\left(\frac{10 \text{ ft}}{3 \text{ pings}}\right)\left(\frac{1 \text{ knot}}{1.68 \text{ ft/sec}}\right) = 5.4 \text{ knots.}$$

Using this procedure, maximum velocities were calculated for two cases: (1) the assumption of one data point per resolution element, with a resolution element defined as target length/3 for the deep scenario and target length/20 for shallow; and (2) the same as (1) with the stipulation that the resolution not be worse than 3 feet.

Table E–4 presents the results for both cases. The more restrictive Case 2 results were used in the AUSS model analysis.

Table E-4. Acoustic link speed limitations for sonar.

Case 1. Forward velocity calculated results assuming lateral resolution = longitudinal resolution = target length/3 for deep case, target length/20 for shallow.

Scenario	Target Length, ft	Swath, ft	Resolution, ft	Sonar Speed, knots
Deep	10	2201	3.33	5.4
	30	5310	10.0	20.1
	100	5310	33.33	224.1
	300	6995	100.0	1531.7
Shallow	10	330	0.5	0.81
	30	990	1.5	2.43
	100	3302	5.0	8.11
	300	3413	15.0	70.63

Case 2. Same as above, but with resolution no worse than 3 feet.

Scenario	Target Length, ft	Swath, ft	Resolution, ft	Sonar Speed, knots
Deep	10	2201	3.0	4.86
	30	5310	3.0	6.05
	100	5310	3.0	20.17
	300	6995	3.0	45.95
Shallow	10	330	0.5	0.81
	30	990	1.5	2.43
	100	3302	3.0	4.86
	300	3413	3.0	14.12

MEAN PERFORMANCE TIME INTERIM RESULTS

The goal of the expressions in Appendix C was to find an optimum number of subcells (N′) into which the overall search cell should be divided in order to minimize the expected performance times. The penalties for chopping the search cell into these subcells vary from system to system. For towed systems and for the acoustic link free-swimmer, the penalty is the phase change in switching from the search to evaluation mode. For the free-swimmer, the penalty is the surface/deck time/dive time cycle required to review data and replenish batteries. Table E-5 presents the calculated N′ values for the six systems that required such a value.

SCAN SIZE ANALYSIS

For any system employing the CURV-type search (a number of circles are searched via a scanning sonar), it is necessary to determine the number of circles or scans required to insure 100 percent coverage of the search cell. Furthermore, for the rf tether link system, it was necessary to determine the number of these circles that could be scanned before it was necessary to replenish the wire spool. Table E-6 summarizes these results, assuming square packing of the circles.

MEDIAN TRAILER VIDEO CALCULATIONS

There are two situations that the towed system with trailer video can encounter: (1) the video vehicle flies over the target, performing immediate contact evaluation, or

Table E-5. Optimum number of subcells (N′) to minimize expected performance times.

Scenario	Target Length, ft	Systems/N′ Baseline Towed	Optimized Towed	Towed/ Clump	Towed/ Video	Free-Swimmer	Acoustic Link Free-Swimmer
Deep	10	9.08[1]	2.08[1]	1.56[1]	1.52[1]	2.94[2]	17.17[3]
	30	7.15	1.56	1.01	0.98	1.78	11.09
	100	5.22	1.36	1.02	0.99	1.56	9.58
	300	3.76	1.17	1.12	1.09	1.54	9.45
Shallow	10	13.21[4]	6.57[4]	4.71[4]	4.49[4]	8.34[2]	81.39[3]
	30	8.16	4.31	2.87	2.51	4.72	29.93
	100	5.21	2.88	1.97	1.73	2.79	18.30
	300	4.04	2.10	1.67	1.40	1.93	16.22

Penalties for subdividing search cell:
[1] 2-hour phase changes
[2] Up-down cycles
[3] 1-minute phase changes
[4] 1-hour phase changes

Table E-6. Scan size parameters.

Area of Search Cell, nmi^2	Target Length, ft	Circle Diameter, ft	Center-to-Center Spacing, ft	Number of Circles for Complete Coverage	Number of Circles per Wire Spool	Number of Dives as Function of Spool Requirements
16	300	6995	4946	25	7[1]	4
	100	5310	3755	49	8[1]	7
	30	5310	3755	49	8[1]	7
	10	2201	1556	256	20[1]	13
10	300	3413	2413	78	21[2]	4
	100	3302	2335	84	22[2]	4
	30	990	700	792	72[2]	11
	10	330	233	6943	215[2]	33

[1] In the deep case, 30,000 feet of wire was assumed for bottom search.
[2] In the shallow case, 50,000 feet of wire was assumed for bottom search.

(2) the target is outside the excursion swath of the video vehicle; delayed contact evaluation is required, but fewer sonar contacts will have to be evaluated because some were already inspected by the video vehicle. A rough average of the two cases can be performed by calculating

$$\text{median time} = \left(\frac{SWV}{SWS} \times \text{immediate time}\right) + \left(1 - \frac{SWV}{SWS}\right)(\text{delayed time})$$

where SWV = the video excursion swath
and SWS = the sonar swath.

These results are summarized in Table E-7.

Table E-7. Median trailer video calculations.

Scenario	Shallow				Deep			
Target length, ft	10	30	100	300	10	30	100	300
Mission time with immediate contact evaluation, hours	33.197	11.160	4.295	2.588	16.019	8.378	8.298	8.262
Mission time with delayed contact evaluation, hours	42.337	16.607	9.821	7.447	18.769	12.154	12.266	13.403
$\frac{\text{Video excursion swath (SWV)}}{\text{Sonar swath (SWS)}}$	1.0	1.0	.4543	.4395	.4543	.1883	.1883	.1430
$1 - \frac{SWV}{SWS}$	0	0	.5457	.5605	.5457	.8117	.8117	.8570
Median mission times, hours $(\frac{SWV}{SWS} \times \text{immediate}) + (1 - \frac{SWV}{SWS} \times \text{immediate})$	33.197	11.160	7.310	5.311	17.519	11.442	11.843	12.668

Assumptions: 1000 - ft trailer swath at 6 knots, deep
1500 - ft trailer swath at 4.25 knots, shallow

CLOCK TIMES

The results of the performance analysis were expressed in terms of expected performance times (or rates) according to the statistical expressions of Appendices C and D. These values were generated from the clock time results output by the AUSS model. "Clock time" in this case means the time it takes to search and evaluate an entire search cell to a probability of detection of 0.9. Table E-8 summarizes the clock time results for all systems. For those systems where an AUSS model run was not conducted, a clock time value was calculated equivalent to the expression for "T_{pass}" in Appendix C. Note that the clock time values ignore and therefore negate the advantages of immediate contact evaluation.

SYSTEMS EXCLUDED FROM ANALYSIS

The seven candidate search systems were selected from approximately thirty concepts that were proposed and considered in a series of engineering evaluation sessions. Systems that were too developmental or which would not (on inspection) offer improvements over the baseline towed system were excluded from further consideration. These excluded concepts and brief rationale for their exclusion are listed in Table E-9.

Table E-8. Clock times for shallow (10 nmi^2) and deep (16 nmi^2) scenarios, hours.

	Shallow				Deep			
Target length, ft	10	30	100	300	10	30	100	300
Systems:								
Baseline towed system	428.45	164.26	67.72	41.29	408.35	255.43	138.79	74.57
Optimized towed system	106.78	46.5	21.44	11.89	25.49	16.16	13.24	10.92
Towed system with decoupling clump	55.34	21.21	10.58	7.97	16.23	9.25	9.36	10.37
Towed system with trailer video/	58.57	20.46	10.89	7.68	19.56	10.87	11.02	13.65
Rf tether link/ CURV type search	153.70	40.22	16.37	14.30	43.47	22.46	22.31	13.16
Free-swimmer	68.28	26.26	11.80	6.85	21.95	11.17	8.83	8.77
Acoustic link free-swimmer	275.74	39.58	14.29	11.29	15.82	8.31	6.47	6.36
Acoustic link free-swimmer/CURV type search	96.09	20.09	9.92	7.85	11.33	6.27	6.12	4.94

Table E-9. Systems excluded from analysis.

Search system concepts excluded from analysis, along with brief rationale for their exclusion, are presented below. Extremely similar concepts in the original evaluation sessions are presented in this table as single concept categories.

System/Concept	Rationale for Exclusion
Simultaneous deployment of more than one search system.	Too obvious to warrant serious consideration. In theory, it works: three search systems operating simultaneously should yield three times the search rate of a single system.
Multiple ships, one towing a sonar vehicle one towing a video vehicle.	An idea that evolved into (and was therefore replaced by) the towed system/trailer video concept.
Multiple ships, the second for laying additional navigation grids.	Again, too obvious for detailed study. If one can afford the luxury, one can slightly reduce the on-scene time. Probably not cost effective.
Air deployable systems.	Difficult for the aircraft to remain on scene the required length of time. No improvement in on-scene search rate; probably some degradation due to difficulty in laying transponder grids.
Submarine deployable systems (free-swimmers).	Useful where covertness is desired or if sea states prohibit use of surface craft, but no improvement offered in search rate.
Towed system with clump; tethered vehicle attached to clump sweeps from side to side to effectively increase sonar swath.	Calculations indicated that attainable search rates weren't competitive with baseline towed system.
Precision large-area search via ship's hull-mounted sonar.	Too developmental.
Messenger floats. (Example: pop-up tape cassettes that bring interim data to the surface while free-swimmer continues its pattern, recording data on additional cassettes.)	Calculations indicated that no significant benefit would have been derived.
Enhanced sonar swaths (including NOSC's ADOSS concept).	Too developmental.
ROMS (NOSC's remote optical mapping system).	As a combination large area-contact evaluation tool, calculations indicated that it wasn't competitive with the usual sonar-video combinations. Would be effective in a strictly evaluation mode, but too developmental.
Smart sidelooker (a sonar aboard a free-swimmer that is capable of independently recognizing a probable target).	Too developmental.
Inertial navigation.	Not sufficiently accurate for typical search durations. It was felt that any benefits from eliminating a navigation system would be offset by navigational inaccuracies.

Table E-9. Systems excluded from analysis (Continued).

System/Concept	Rationale for Exclusion
Sonar image enhancement.	Team members felt that considerable effort should be spent in this area, particularly for side-looking sonars. The work is necessary and is hopefully not too developmental. The concept was not modeled, however, because the AUSS model assumes that the given sonar works. The problem would have been to model the human interface.
Cooperative targets (pingers, etc.)	Most high value targets avoid the use of locaters; they prefer to "stay lost." If the target is to be cooperative, it should be sufficiently cooperative that "search" isn't necessary.
Rocket deployed system/satellite navigation/data radioed back to land-based analysis center.	Science fiction at this stage. Too developmental.
Glide body evaluation vehicle. (When a contact is observed on SLS, one of a series of free-flight vehicles with still camera deploys and glides over suspected contact.)	Too developmental. Far too many glide bodies would be required in the shallow case. The desired evaluation service is essentially performed by the "towed body/trailer video" system.
Single bottom navigation pod versus transponder grid. (Only range data is recorded; evaluation vehicle returns and evaluates entire circle at proper radius.)	Possibly works, but wouldn't improve the on-scene performance. Also, horizontal paths are more difficult.
Acoustical holographic search system.	Too developmental.
Manned submersibles.	Originally, outside the scope of the present AUSS analysis. If a manned submersible had sufficient speed (up to 10 knots), it would essentially be a "smart" free-swimmer, and should therefore constitute the best available search system. It could also be outfitted to do work, etc., the only drawbacks being the cost and the risks to human life. Present manned submersibles are low speed, slower than the baseline towed system, and are therefore not competitive.
Mammals.	Could be trained to do an effective job in shallow scenarios, but not applicable to deep case.

APPENDIX F
OVERALL MISSION TIMES AND DEBRIS FIELDS

This appendix contains discussions of overall mission times (including contributions other than on-site factors) and of optical searches for debris fields.

MOBILIZATION, DOWN TIME, NAVIGATION GRIDS, STEAMING

The on-scene mission time is often only a small part of an overall search operation. Considerable time is consumed in planning and mobilization, steaming to the search site, laying navigation grids, and down time at the site for repairs, weather, etc.

A review of past search operations indicates that searches can be roughly (very roughly) categorized into two types: "short" (those that take about a week) and "long" (those that take about a month). A given search can be broken down as follows.

$$T = nKt + M + nG + \frac{D}{V} \tag{1}$$

where T is the mission time in hours

n is the number of cells to be searched (1 navigation grid per cell)

K is the down-time factor (for repairs, weather, etc.)

t is the time to search a single cell, in hours

M is the mobilization/planning time, in hours

G is the time to lay a single navigation grid, in hours

D is the steaming distance, in nautical miles

V is the steaming velocity, in knots.

Assigning values that correspond (as examples) for each of the "two" cases, we have:

SHORT MISSION

$$T = (1)(1.1)(\ t\ ) + 48 + (1)\,(12) + \frac{500}{12} \tag{2}$$

LONG MISSION (1 SEARCH CELL)

$$T = (1)(1.15)(\ t\ ) + 120 + (1)\,(12) + \frac{1200}{12} \tag{3}$$

LONG MISSION (7 SEARCH CELLS)

$$T = (7)(1.15)(\ t\ ) + 120 + (7)\,(12) + \frac{1200}{12} \tag{4}$$

Note that the values used above are examples only. Adverse weather could easily up the 1.1 or 1.15 "down-time" factors; a different locale (suppose the target were off the opposite coast!) could easily up the 1200 nautical miles.

Tables F-1 and F-2 present the total mission times for the baseline towed system and the seven candidate systems, generated by plugging the appropriate on-scene mission times (t) into equations 2 through 4. As expected, the considerable weighting factor introduced by the "nonproductive" portions of the mission significantly reduces the gains that were achieved in the on-site search rate.

Table F-1. Total mission times (hours) for typical short search mission, shallow scenario.

	One Search Cell			
Target length, ft	10	30	100	300
Systems:				
Baseline towed system	425.8	234.7	161.8	140.9
Optimized towed system	191.6	144.9	124.3	115.8
Towed system with decoupling clump	152.0	124.1	114.5	112.0
Towed system with trailer video (median)	138.2*	113.9*	109.7	107.5*
Rf tether link/ CURV type search	206.1	129.9	112.7	111.3
Free-swimmer	161.5	129.1	117.0	112.8
Acoustic link free-swimmer	290.3	130.1	114.0	111.8
Acoustic link free-swimmer/CURV type search	167.3	116.2	109.4*	107.9
*Maximum improvement	*3.1*	*2.1*	*1.5*	*1.3*

This apparent loss of search rate gain is of course subjective. For some searches, the mobilization time is irrelevant because there is no hurry to find the target. The only relevant factor in this case is the cost effectiveness of the on-site search.

When mobilization and steaming are relevant, some systems might perform better than others. The most efficient scenario would include a stand-by trained crew with a fly-away system (such as one of the free-swimmers). A system with reduced navigation requirements, such as the acoustic free-swimmer/CURV search mode, might allow the use of a short baseline system, even further reducing the overall mission time.

Although the considerations of the above paragraph could be quantitatively examined, the dominant values of equations 2 through 4 are so arbitrary that further analysis is of questionable value. Suffice it to say that these considerations should be addressed during an actual system design.

DEBRIS FIELDS

For all the cases analyzed, it was assumed that the target was a single, intact object, and that the search would be conducted in two phases: (1) a broad-area sonar search followed by (2) a video contact evaluation search.

In some searches, the above scenario doesn't apply. Often, the target is a broad debris field for which an optical broad-area search is required. In this case, the target

Table F-2. Total mission times (hours) for typical long search missions, deep scenario.

	One Search Cell				Seven Search Cells			
Target length, ft	10	30	100	300	10	30	100	300
Systems:								
Baseline towed system	500.8	382.5	289.7	236.4	2689.8	1861.7	1212.0	838.7
Optimized towed system	191.8	181.3	179.1	176.4	526.7	460.2	437.8	418.9
Towed system with decoupling clump	182.4	173.7	174.5	175.1	460.7	404.6	405.6	414.4
Towed system/ trailer video (median)	180.1	173.1	173.6	174.6	445.0	396.1	399.3	405.9
Rf tether link/ CURV type search	192.1	177.4	176.5	169.3	529.1	426.1	424.9	369.3
Free-swimmer	186.9	174.8	171.5	171.0	492.3	412.6	385.1	384.5
Acoustic link free-swimmer	173.4	167.5	166.2	166.1	397.7	358.6	347.2	346.6
Acoustic link free-swimmer/CURV type search	169.4*	165.9*	165.5*	164.7*	369.9*	345.4*	344.3*	338.7*
*Maximum improvement	2.9	2.3	1.7	1.4	7.3	5.4	3.5	2.5

is considerably easier to locate, in spite of the narrower optical swaths. As an example, a situation was generated in the AUSS model where a 10-foot object was sought in a shallow scenario with a free-swimmer in the standard search mode (broad-area sonar search first, followed by video contact evaluation). The target was then replaced by a half-mile long debris field, and broad-area search was conducted with a visual sensor. Table F-3 summarizes the results.

The larger the debris field, of course, the higher the performance rate. Of all the candidate systems, only the towed system with the trailing video vehicle would simultaneously scan for a debris field. This system would therefore have an advantage in the situation where an intact target is suspected, but a debris field actually exists.

If a debris field is known to exist, the systems with an inspection capability have the additional advantage of being able to hover selectively over given areas, either for a better video perspective or for enhanced photographic coverage. These systems include all the advanced towed systems, the rf tether link system, and the acoustic link free-swimmers.

Table F-3. Debris field results.

Scenario/System	Sensor	Target	Mission Rate*, nmi^2/hour
Shallow free-swimmer	(1) Side look sonar (2) SIT camera	10 - ft long Intact object	0.0775
Shallow free-swimmer	SIT camera	½ - mile long debris field	0.5218
Shallow free-swimmer	NRL wide angle camera	½ - mile long debris field	0.5219**

*These are AUSS model clock time values, not expected performance rates.
**Excludes time to process and inspect film.

APPENDIX G
TOWED SYSTEM PERFORMANCE RESULTS

Most deep ocean search performed today is conducted with towed search systems. A typical system consists of a single tow body with a side-looking-sonar video, and photographic cameras. For small, intact targets, large area search is conducted first with the side-looking-sonar, and then contact evaluation is performed on promising sonar contacts with the video/photographic cameras.

During the current AUSS study, a typical (baseline) towed system was analyzed along with three candidate towed systems. The candidate systems featured specific capabilities that ultimately offered improved search rates relative to the baseline system search rate. This appendix reviews the basic descriptions of these four towed systems and their projected performances.

Figures G-1 through G-5 illustrate the candidate towed systems. Relative to the baseline-towed system, all of the systems feature a smaller vehicle control error (for towed systems, 200 feet in the deep case as opposed to the 600-foot baseline value; with no change in the shallow case; control error is assumed to be 0 feet for free-swimmers), more precise navigation (15 feet rms error as opposed to the baseline error of approximately 60 feet), and a slightly shorter launch time (15 minutes as opposed to the baseline 30 minutes). These features offered only slight improvements in the mission rates; more significant features are discussed below as a function of each system.

OPTIMIZED TOWED SYSTEM

The system illustrated in Figure G-1 is essentially the same as the baseline towed system, with two major exceptions: (1) higher speeds are possible by using a faired cable, and (2) turn times are reduced to 0 by using a rectangular spiral search pattern with computer-aided ship turns (computer-aided ship navigation is used to keep the vehicle on an exact track).

TOWED SYSTEM WITH DECOUPLING CLUMP

All of the above features are incorporated, with the additon of the following: (1) the vehicle is decoupled from the faired tow cable via a depresser clump in order to reduce vehicle control error; the vehicle maneuvers itself in the search phase via control surfaces (Figure G-2); and (2) in the evaluation phase, the vehicle maneuvers via an active thruster; it is guided to the target via a scanning sonar mounted beneath the depresser clump (Figure G-3). This latter feature reduces navigation error to 0 during final approach. The active thruster mode also offers a controlled inspection capability.

TOWED SYSTEM WITH TRAILER VIDEO

All of the above features are incorporated, with the addition of a small, laterally mobile vehicle with video/photographic capability (Figure G-4). This vehicle trails behind the primary sonar vehicle, translating from side to side so that it flies over promising sonar contacts moments after they appear on the sonar screen. In essence, immediate contact evaluation is performed, with no time penalties, assuming that the sonar swath is relatively narrow. For larger sonar swaths, where the geometry of the situation prohibits complete video coverage of all sonar contacts, the trailing video vehicle will still scrutinize *some* of the

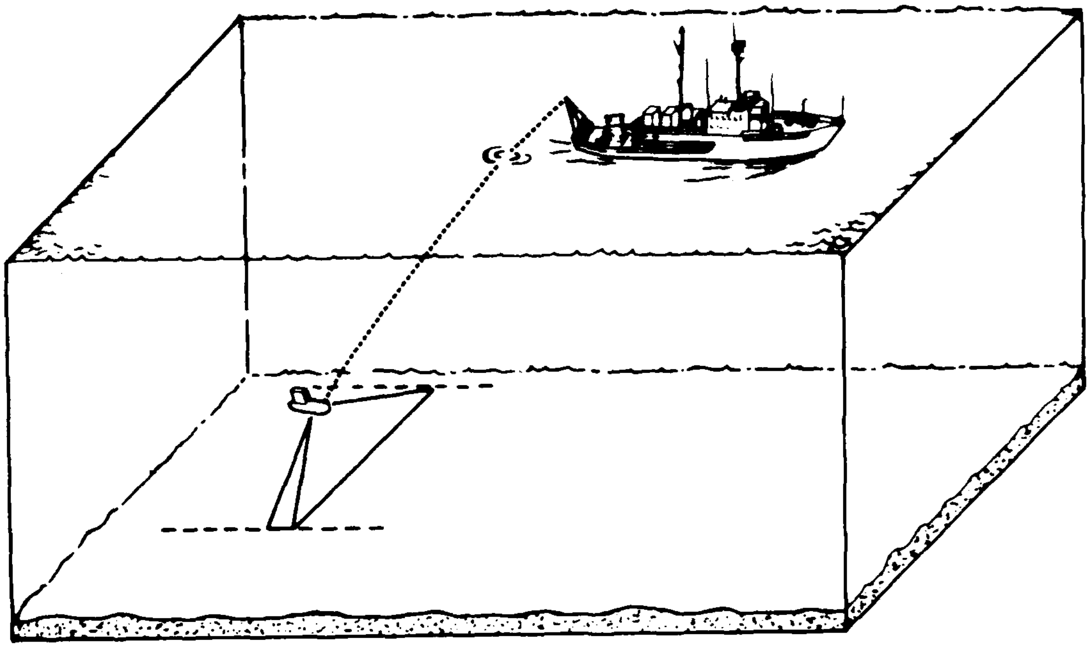

Figure G-1. Optimized towed system.

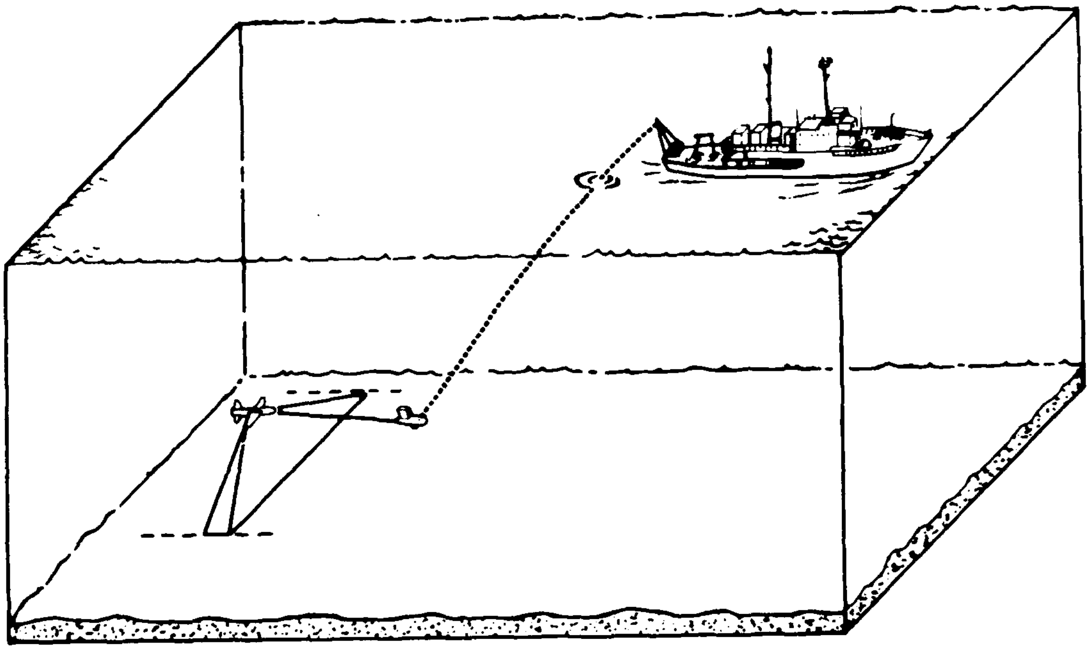

Figure G-2. Towed system with decoupling clump (search phase).

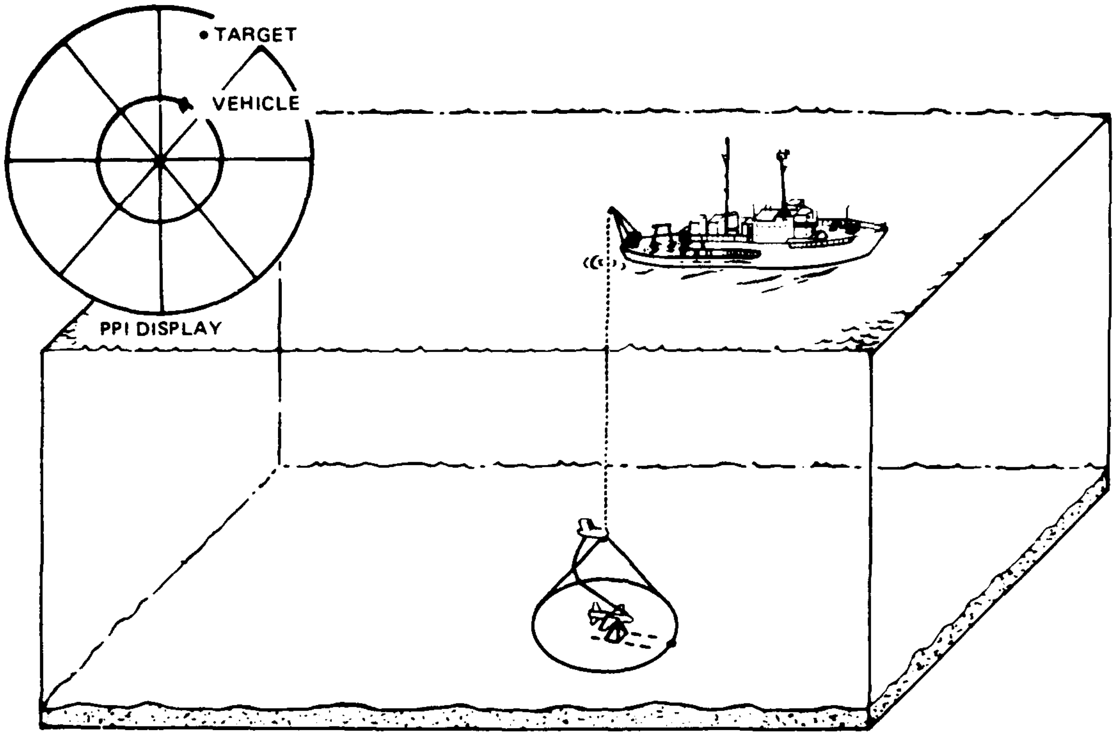

Figure G-3. Towed system with decoupling clump (evaluation phase).

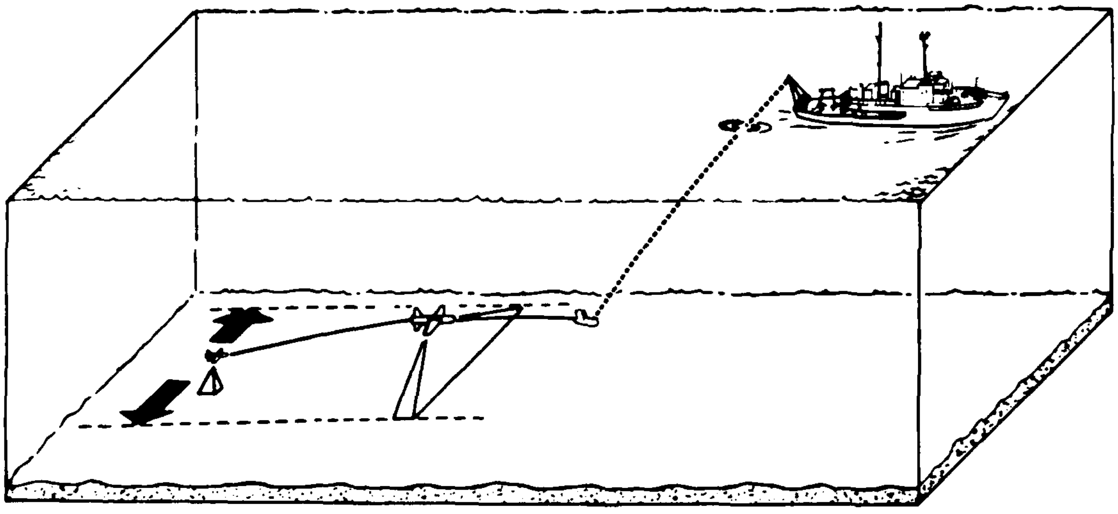

Figure G-4. Towed system with trailer video (search/immediate contact evaluation phase).

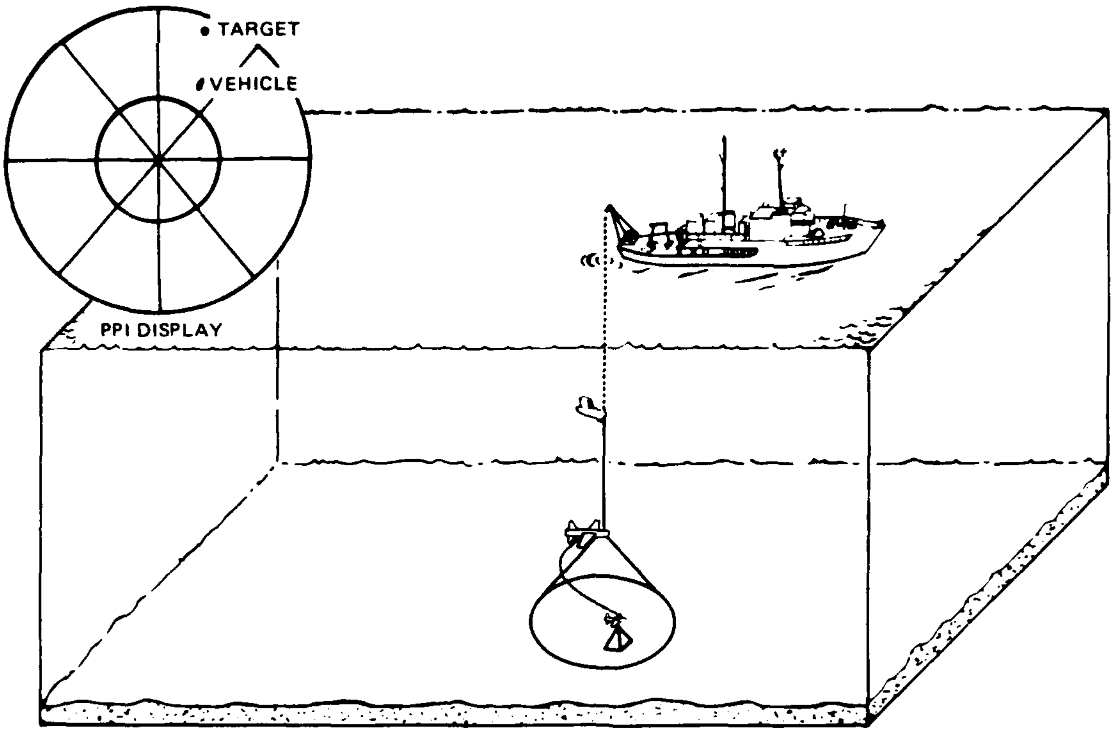

Figure G-5. Towed system with trailer video (delayed evaluation phase).

sonar contacts, reducing the number required to examine during a classic contact evaluation phase. During formal contact evaluation (Figure G-5), the video vehicle will perform its task under scanning sonar navigation, as per the previous system concept.

RISK ANALYSIS

Although all candidate towed systems involve state-of-the-art components or techniques, each incorporates certain critical technologies that will require special attention during fabrication and testing. System characteristics, advantages, and critical technologies are summarized in Table G-1.

PERFORMANCE ANALYSIS

All towed systems were analyzed via the AUSS model to determine on-site mission rates (in square nautical miles per hour) for each. Specifically, the expected performance times were calculated via the AUSS model results and the statistical expressions of Appendices C and D. These times were divided into the area of the appropriate scenario to determine the on-site mission rates. Results are tabulated in Table G-2 for target lengths of 10, 30, 100, and 300 feet for both the shallow (2000 feet) and deep (20,000 feet) scenarios. For ease in interpreting the data, Table G-2 results are plotted in Figures G-6 and G-7.

As shown, each system improvement led to improved search rates, for both scenarios and for all target sizes. The faster tow speeds and larger sonar swaths in the deep scenario led to considerably better search rates in the deep case. (Tow speeds were sensor limited in the shallow case; the scarp terrain associated with the shallow scenario led to smaller sonar swaths than those obtainable with the smooth terrain associated with the deep scenario.)

Table G-1. Candidate towed systems.

System	System Characteristics	Advantages	Critical Technology
Optimized Towed System	Faired cable for higher speeds Computer-aided ship turns for zero turn times	Builds on existing search system technology and techniques Higher speeds, zero turn times	Faired cable with high-speed winch High-speed bottom following Computer-aided ship turns Suitable ship availability
Towed system with decoupling clump	Faired cable for higher speeds Computer-aided ship turns for zero turn times Decoupled sensor vehicle with passive vane control for search, active control for evaluation Scanning sonar on clump	Higher speeds, zero turn times Zero control error Easier computer-aided ship turns Minimal ship towing during evaluation Zero navigation error during final evaluation coverage Video inspection capability Reduced high-speed bottom following risk because of control surfaces in search phase and because not required in evaluation phase	Faired cable with high-speed winch High-speed bottom following (lesser risk than above system) Computer-aided ship turns Suitable ship availability
Towed system with trailer video	Faired cable for higher speeds Computer-aided ship turns for zero turn times Decoupled search sensor vehicle with passive vane control for search, active control for evaluation Scanning sonar on clump	Higher speeds, zero turn times Zero control error Easier computer-aided ship turns Minimal ship towing during evaluation Zero navigation error during final evaluation coverage Video inspection capability	Faired cable with high-speed winch High-speed bottom following Computer-aided ship turns Suitable ship availability

Table G-1. Candidate towed systems (Continued).

System	System Characteristics	Advantages	Critical Technology
	Additional small, laterally mobile video vehicle	Immediate contact evaluation with no time penalties (best case) or reduced contact evaluation time (worst case) Immediate video correlation with sonar (on-scene sonar training)	

Table G-2. Expected search rates (nmi^2/hr) for shallow and deep scenarios.

	Shallow				Deep			
Target length, ft	10	30	100	300	10	30	100	300
Systems:								
Baseline towed system	0.0339	0.0827	0.1828	0.2802	0.0540	0.0827	0.1418	0.2409
Optimized towed system	0.1223	0.2539	0.4861	0.7788	0.5785	0.8247	0.9627	1.1204
Towed system with decoupling clump	0.2187	0.4899	0.8540	1.0638	0.8218	1.2800	1.2678	1.1662
Towed system with trailer video/ immediate evaluation	0.3013	0.8961	–	–	–	–	–	–
Towed system with trailer video/ delayed evaluation	–	–	1.0183	1.3423	0.8524	1.3169	1.3050	1.1940
Median trailer* video rates	0.3013	0.8961	1.368	1.883	0.9152	1.3986	1.3514	1.2628

*See Appendix E.

The improvements obtained by the candidate systems are presented in Table G-3 as ratios of search rates obtained with the candidate systems relative to those obtained with the baseline system. As shown, significant improvements can be obtained, particularly in the deep scenario, through the use of the proposed concepts.

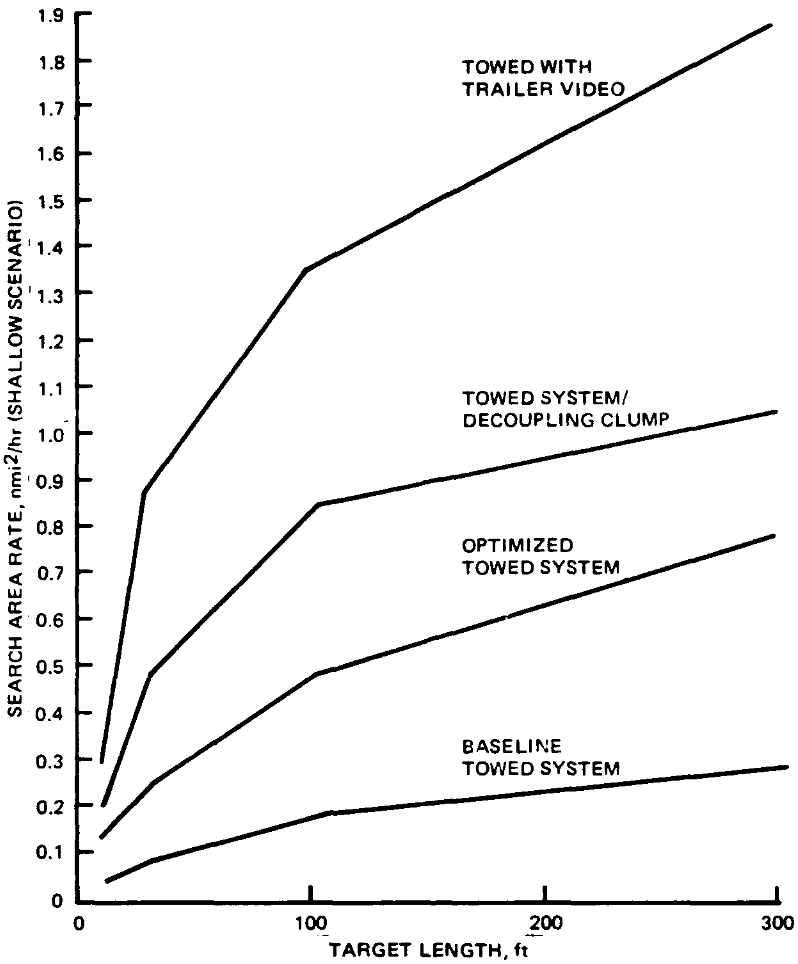

Figure G-6. Search area rates versus target length, shallow scenario.

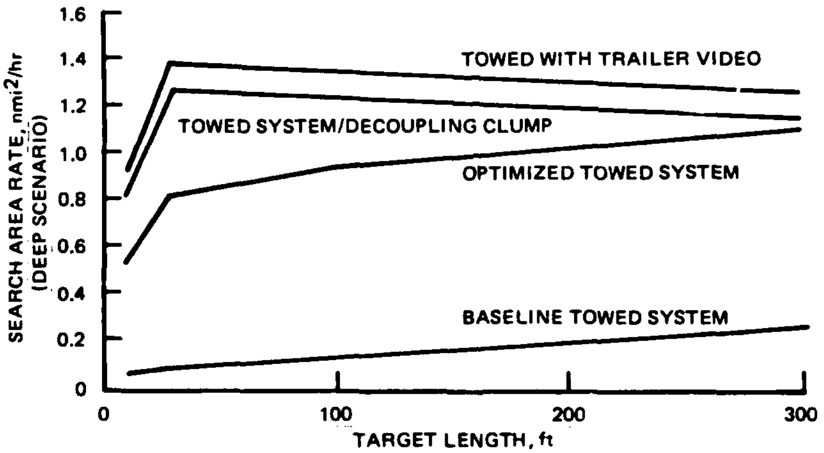

Figure G-7. Search area rates versus target length, deep scenario.

Table G-3. Ratio of advanced system search rates to baseline towed system search rate for shallow and deep scenarios.

	Shallow				Deep			
Target length, ft	10	30	100	300	10	30	100	300
Systems:								
Baseline towed system	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Optimized towed system	3.6	3.1	2.7	2.8	10.7	9.9	6.8	4.6
Towed system with decoupling clump	6.5	5.9	4.7	3.8	15.2	15.4	8.9	4.8
Towed system with trailer video/ immediate evaluation	8.9	10.8	–	–	–	–	–	–
Towed system with trailer video/ delayed evaluation	–	–	5.6	4.8	15.8	15.9	9.2	4.9
Median trailer video ratio	8.9	10.8	7.5	6.7	16.9	16.9	9.6	5.2